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AFWAL-TR-80-4027

CRITICALLY LOADED HOLE TECHNOLOGY
ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

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George Roth (Univ. of Dayton Research F33615-78-C-5030/ Jul PERFORMING ORGANIZATION NAME AND ADDRESS 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Metcut Research Associates Inc. 3980 Rosslyn Drive Cincinnati, OH 45209 CONTROLLING OFFICE NAME AND ADDRESS Materials Lab (AFWAL/MLSA) Mar \$380 Air Force Wright Aeronautical Labs Air Force Systems Command Wright-Patterson AFB, OH 45433
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FOREWARD

A thirty (30) month pilot test program was conducted which consisted of a coordinated test activity between interested NATO/AGARD SMP member countries including Sweden as a non-member country. This pilot program lead to a more uniform attitude toward fatigue testing and evaluation of critically loaded hole parameters among its participants. This report describes the US portion of a complex test program where each new phase was initiated after the successful completion of the previous phase. The program was conducted under Air Force Contract No. F33615-78-C-5030. The program manager for the Air Force Wright Aeronautical Laboratories was Mr Robert Urzi. The prime contractor was Metcut Research Associates Inc. in Cincinnati, Ohio under the direction of Mr John B Kohls. Subcontractors to Metcut were: Battelle-Columbus Laboratories (Mr Stephen Ford) in Columbus, Ohio which conducted all spectrum fatigue testing and University of Dayton Research Institute (Mr George Roth) in Dayton, Ohio which performed the load verification effort.

Contribution of fastener equipment and installation techniques included Messrs. Paul Pagel of Kaynar, Fullerton, California and Patrick Meade of Monogram/Aerospace Fasteners, Los Angeles, California.

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TABLE OF CONTENTS

SECTIO	ON .	PAGE
I	PROGRAM DESCRIPTION	1
II	MATERIALS AND SPECIMENS	3
III	CONCLUSIONS	8
	APPENDIX A	22
	APPENDIX B	25
	APPENDIX C	28
	APPENDIX D	45
	APPENDIX E	89
	APPENDIX F	116

LIST OF ILLUSTRATIONS

IGURE		PAGE
1	Test Coupon Layout - Phase 1 Specimens	10
2	Test Coupon Layout - AGARD - Critically Loaded Hole Technology, Phase 2	11
3	Test Coupon Layout - Phase 3 Specimens	12
4	Schematic of Packaging for Phases 1A and 2 Specimens and Phase 3 Material	13
5	Reverse Dogbone Specimen Used for Phase 3	14

LIST OF TABLES

TABLE		PAGE
1	Mechanical Properties 7050-T76 Aluminum Alloy	15
2	Machining Conditions Used for Face Milling the Specimen Blanks	16
3	Machining Conditions Used for Milling the Specimen Contour	17
4	Drilling Conditions Used for Center Notch Test Holes	18
5	AGARD SMP Critically Loaded Hole Technology Specimen Number Identification	19
6	Reverse Dogbone Specimens Identification and	21

SECTION I

PROGRAM DESCRIPTION

1. PHASE 1

The aim and purpose of Phase 1 and Phase 1A (Phase 1 repeat) was to substantiate the thesis that in spite of idiosyncrasies in fatigue testing occurring in widely separated mechanical testing laboratories, fatigue testing of identical specimens, utilizing similar testing parameters, e.g. load history, physical/chemical environment, etc., would lead to mutually agreeable conclusions. The thesis was stated with the stipulation that all test samples were identical in physical, mechanical, and geometric properties.

2. PHASE 2

From the data submitted on Phase 1 and preliminary analysis of the data, a major restructuring of the Pilot Test Program took place. Added to the program was a complete replication of the Phase 1 test effort. This replication took place concurrent to the Phase 2 test activity. Phase 2 was modified as to content and level of effort required. Retained from the original program was the definition of two levels of hole quality (cost) reflecting each participant's aerospace industry. Taking advantage of the Phase 1 results and with the replication of the Phase 1 testing, the concept of round-robin testing was not used for the Phase 2 activity. It was felt that the homogeneity of variance exhibited in Phase 1 data which was further densified by repeating the Phase 1 tests enabled each country to work independently in Phase 2. However, common materials and a single source of specimen blanks was used in Phase 2. Each participant fabricated their own test coupons from specimen blanks provided by the

U. S. Each participant fabricated six specimens containing a high quality (cost) hole and ten specimens containing a low quality (cost) hole. These specimens were subsequently fatigue tested as "open hole" coupons.

Concurrently with the tests on the sixteen specimens, six repeat specimens, identical to Phase 1 specimens, were also tested. It was felt that this approach enabled the concept of round-robin testing to be dropped. This approach also provided a better basis for the unaltered concept of the Phase 3 program. It enables the participants to compare the ratios determined in Phase 3 with those arrived at in Phase 2. In addition to retaining the original scheduling proposed for Phases 2 and 3, this concept provided a reduction in the total number of specimens manufactured and tested by each participant.

3. PHASE 3

In this phase the work developed into separate programs, each program being undertaken by one participant and being complete in its own right. Each participants program determined the fatigue performance of one (his choice) structural fatigue rated fastener system installed in a high or low quality hole (by his own definition). It also studied a non-fatigue rated fastener alternative of the same static strength assembled with low quality holes. Phase 3 utilized a low load transfer joint specimen, assembled utilizing standard acceptable joining and faying surface practices. However these faying surface conditions and specimen geometry were identical for all participants.

SECTION II

MATERIAL AND SPECIMENS

The material used on the AGARD SMP Critically Loaded Hole Technology Program was 7050-T76 wrought aluminum alloy. This material was received in mill rolled sheets approximately .197" x 44.5" x 96" in size. There were two heats of material on the program. Heat No. 1 designated as Lot 302-791 was used in Phases 1, 1A, and 2 test activity. Heat No. 2 designated as Lot 219-521 was used only in Phase 3. The chemical composition and mechanical properties as supplied by the basic metal producer (Aluminum Company of America) are given in Table 1. Since the specimens were to be tested in the "as received" or "as milled" condition, the sheets of aluminum alloy were procured with protective coating on each side to prevent scratching or other surface blemishes during shipment.

Sketches showing the layout of the specimens used on the program are presented in Figures 1, 2, and 3. The specimen lengths were cut out using a Grob band saw cutting at approximately 300 ft./min. After cut out, the edges, both length and width, were face milled using the conditions given in Table 2. This was followed by contouring the gage section area per the condition given in Table 3.

The test hole, located in the center of the gage section was produced with a variety of techniques over the three phases of the program.

Phases 1 and 1A test holes were drilled plus double reamed. Phases 2 and 3 used high and low quality holes per consensus of U. S. Aerospace Standards. The procedures for producing these holes are given in Table 4.

The basis for defining high and low quality was cost. The high quality holes were produced by a technique to simulate a Gemcor or other heavy duty automatic drilling machine. A Cincinnati Cinova 80 milling machine was used to assure spindle rigidity similar to a Gemcor. The drill runout did not exceed + .0005 inch. The specimen to be drilled was securely clamped to the machine tool table with a clamping pressure greater than 170 psi. The specimen was located on a special fixture to insure that the test hole was central with respect to both axis of the specimen. The drill geometry and machining conditions are given in Table 4. It is important to note that the high quality condition included a positive power feed rate and spray mist cutting fluid. After drilling, the test hole was not deburred.

The low quality holes were produced on a light duty, tool room type drill press. The specimen to be drilled was not clamped to the table, but allowed to "float" during the drilling operation. A standard jobbers length drill was used with a heavy manual feed rate. The drilling operation was performed without the use of a cutting fluid.

After drilling the low quality test hole but before the drill was extracted from the hole, the spindle was stopped. The drill was then extracted from the hole without rotating. The buildup that had collected on the cutting edges of the tool was allowed to rub along the test hole surface. The geometry and drilling conditions used to produce the low quality holes is given in Table 4.

After fabricating the holes for specimens used in Phases 1, 1A, and 2, the edges of the gage area were radiused using a carbide form cutter having a 1/32" radius. This operation was followed by longitudinal polishing of the gage area using 180 grit aluminum oxide paper. Test specimens were shipped to each participant listed in Table 5. Each country listed received: (1) specimens, (2) an explanatory letter, and (3) a packing slip identifying their particular specimens. A copy of the letter sent to each participant is given in Appendix A.

The Phase 2 specimen configuration was the same as for Phases 1 and 1A specimens. However, the center hole specimen blanks for Phase 2 testing had only a 1/16" pilot hole. These Phase 2 specimens were completed to the final configuration by the individual participants. Along with the specimens for Phases 1A and 2, two 4' x 8' aluminum plates were shipped to each participant for use in the manufacture of joint specimens to be tested in Phase 3.

Figure 4 is a sketch of the packaging of the aluminum plates and test specimens for Phase 2 shipment. A 1/2" sheet of plywood, 4' x 8', was laid on three 2" x 4" rails. The two aluminum plates (4' x 8') were then laid on the top of the plywood. A second sheet of plywood covered the aluminum plates. This second sheet of plywood had a pocket cut out of the center for locating the specimens. A 1/8" piece of plywood was first put into this pocket to separate the aluminum plates from the test

specimens. The specimens were placed on top of this 1/8" sheet and covered by another 1/8" sheet. This entire package was then covered by a third 1/2" sheet of plywood and fastened in place by steel strapping. The cross section of this stack up is given in Figure 4. This packaging procedure insured that the surface of the test specimens would not be blemished during shipment.

The specimens used in the Phase 3 portion of the program were low load transfer joint (reverse dogbone) specimens. A sketch of the specimens configuration is shown in Figure 5. These specimens received a faying surface sealant. This sealant was PR-1431-G and was manufactured by Products Research & Chemical Corporation, Gloucester City, NJ. The specification for use and description of this product as supplied by the sealant manufacturer is given in Appendix B. A procedure for installing this sealant on the fay surface was sent to each of the participants. This procedure is also given in Appendix B.

The phase 3 specimens were of three varieties:

- 1. High quality hole with a fatigue enhancement fastener (K-Lobe fastener system manufactured by the Kaynar Company)
- 2. Low quality hole with a fatigue enhancement fastener (K-Lobe)
- 3. Low quality hole with a blind rivet (VisuLok manufactured by the Monogram Fasteners, a division of Monogram Industries)

The table giving the specimen number along with hole diameter and interference or clearance value for each of the specimens tested in Phase 3 is given in Table 6. The test results for Phases 1, 1A, 2, and 3, are given in reports by the Battelle-Columbus Labs. These reports are in Appendices C, D, and E, respectively.

A final portion of the program was the verification of loading accuracy for the Falstaff load sequence. This work was performed by the University of Dayton Research Institute (UDRI). Personnel from UDRI visited each of the participants and monitored their spectrum fatigue test equipment during test using the Falstaff load sequence program. A report on this load sequence and load level verification is given in Appendix F.

CONCLUSIONS

- 1. The use of widely separated and different National test facilities following the same basic test procedures and test techniques can lead to mutually agreeable test results among investigators provided there is a formal agreement prior to fatigue testing.
- 2. The need for round-robin testing can be minimized or even eliminated providing certain parameters are kept constant or provided to each individual participant. Sufficient accuracy checks during dynamic testing are absolutely essential.
- 3. The terms "high" and "low" quality holes did not lead to equivalent fatigue test results. By U.S. Aerospace Standards for low and high quality holes, the high quality hole leads to substantially longer test lives during the Phase 2 "open hole" program.
- 4. The results obtained during the Loading Verification activity provided data that the testing organization applied the correct loads of the Falstaff Spectrum in conducting fatigue tests for Phase 3 of this pilot program.
- 5. The use of the Kaynar K-Lobe fastener system leads to equivalent fatigue lives in testing low load transfer joint specimens when using both the low level and high level of hole quality. K-Lobe fasteners

were installed in interference fits ranging 0.0041 to 0.0045 inches in high quality holes and interference fits ranging from 0.0036 to 0.0045 inches in low quality holes. The use of a non-fatigue rated blind rivet system in low quality holes leads to very short fatigue lives. Those blind rivets were installed in clearance fit holes of low quality.

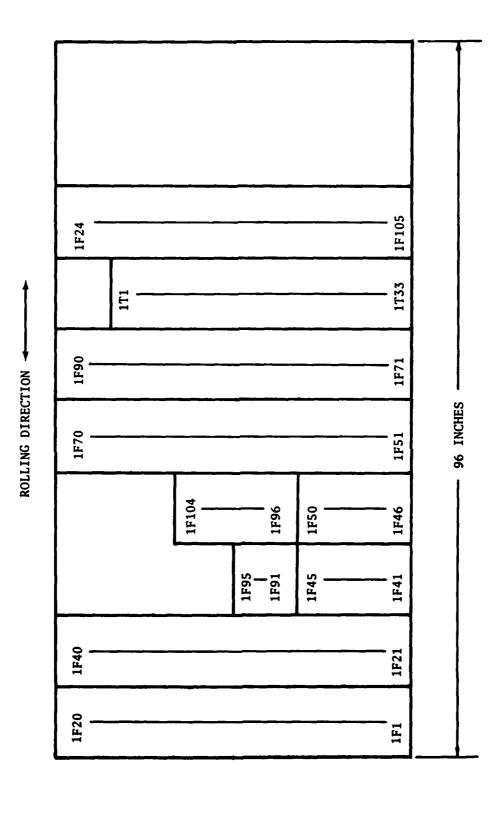
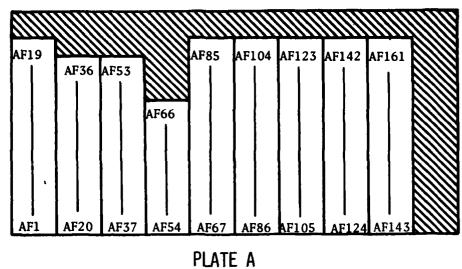


Figure ... Test Coupon Layout - Phase 1 Specimens







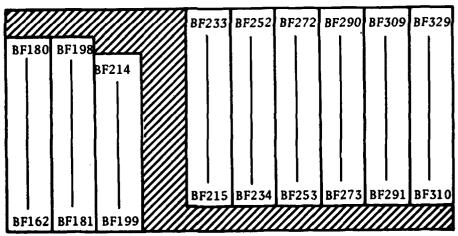


PLATE B

Figure 2 - Test Coupon Layout - Agard - Critically Loaded Hole Technology Phase 2

LONGITUDINAL ROLLING DIRECTION

	J4	J3	J2	J1
	J8	J7	J6	J5
	J12	J11	J10	J9
	J16	J15	J14	J13
Γ.	J20	J19	J18	J17
	J24	J23	J22	J21
	J28	J27	J26	J25
	J32	J31	J30	J29
	J36	J35	J34	J33
	J40	J39	J38	J37
	J44	J43	J42	J41

44 of 46 Pieces #J1 - J44

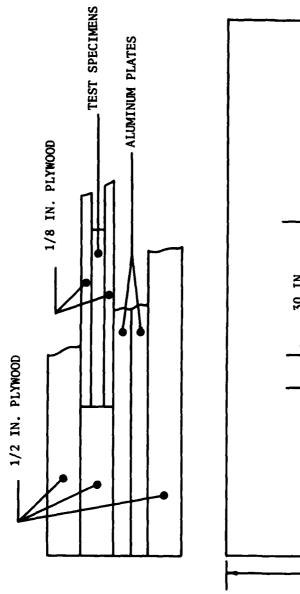
LONGITUDINAL ROLLING DIRECTION

J56	J45
1	J46
1	J47
i	J48
!	J49
i	J50
į	J51
i	J52
i i	J53
	J54
	J55

12 of 56 Pieces

#J45 - J56

Figure 3 - Test Coupon Layout - Phase 3 Specimens



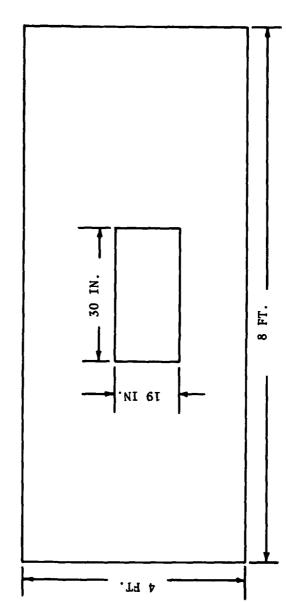


Figure 4 - Schematic of Packaging for Phases 1A and 2 Specimens and Phase 3 Material

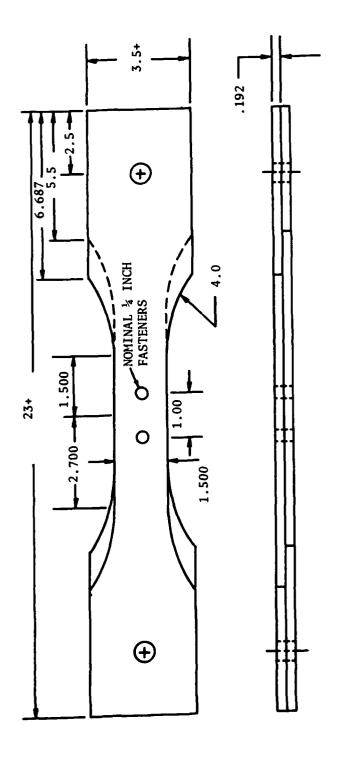


Figure 5 - Reverse Dogbone Specimen Used for Phase 3 (All Dimensions are in Inches)

TABLE 1

MECHANICAL PROPERTIES 7050-T76 ALUMINUM ALLOY

	Lot 3	1, 1A, 2 02-791 Shipment	Lot 2	se 3 19-521 Shipment
	Max.	Min.	Max.	Min.
Tensile Strength, ksi Yield Strength, ksi Elongation, % in. 2 in. Conductivity	85.9 80.2 12.0	85.4 79.3 12.0 35.4	83.7 75.7 12.5	83.2 75.7 12.0 37.5
Composition	Max.	Min.	Max.	Min.
Silicon Iron Copper Manganese Magnesium Chromium Zinc Titanium Zirconium Others, each	0.12 0.15 2.6 0.10 2.6 0.04 6.7 0.06 0.15	2.0 - 1.9 - 5.7 0.08	0.12 0.15 2.6 0.10 2.6 0.04 6.7 0.06 0.15	2.0 - 1.9 - 5.7 - 0.08

TABLE 2

MACHINING CONDITIONS USED FOR FACE MILLING THE SPECIMEN BLANKS

Cutter Diameter, in. 6

Tool Material K68 Carbide

Feed, in./tooth .004

Cutting Speed, ft./min. 1200

Tool Wear, max. .006

No. of Teeth 8

Fluid 20:1 Soluble Oil

TABLE 3

MACHINING CONDITIONS USED FOR MILLING THE SPECIMEN CONTOUR

Cutter Diameter, in.	1
Tool Material	M2 HSS
Feed, in./tooth	.0014
Cutting Speed, rpm	950
Tool Wear, Max.	.006
No. of Teeth	6
Fluid	Drv

TABLE 4

DRILLING CONDITIONS USED FOR CENTER NOTCH TEST HOLES

Phases 1 and 1A

- 1) Drill @ 660 rpm, .002 in. per revolution, 7/32 in. diameter hole
- 2) Ream @ 660 rpm, hand feed, .243 in. diameter hole
- 3) Ream @ 660 rpm, hand feed, .251 in. diameter hole

Phases 2 and 3

High Quality

Tool Material = HSS

Diameter = 6.35 mm.

Geometry:

Point Angle = 140°

Type Point = Crankshaft (split)

Helix Angle = 30°

Spindle Speed = 3000 RPM Feed Rate = .076 M./min.

Cutting Fluid = LPS #1 (Mist)

Type Tool = Heavy Duty Stationary

Equipment

Low Quality

Tool Material = HSS

Diameter = 6.7 mm. (for Fasteners,

6.35 for open

hole)

Geometry:

Point Angle = 118°

Type Point = Crankshaft (split)

Helix Angle = 30°

Spindle Speed = 800 RPM

Feed Rate = Heavy Manual

Cutting Fluid = Dry

Type Tool = Light Duty Drill Press

TABLE 5

AGARD SMP CRITICALLY LOADED HOLE TECHNOLOGY SPECIMEN NUMBER IDENTIFICATION

	PHASE 1									
		Belgium	France	Germany	Italy	Netherlands	Sweden	Turkey	Kingdom	State
	Tensile	174 1710	176	171 178	1T22 1T23	172 1713	1T9 1T12	1727	1T3 1T5	1T19 1T24
		1117	1.T.14	1722	1726	1715	1T16	1733	1718	1T30
	Fatigue	1F17	1F48	1F6	1F35	1F31	1F9	1F4	1F20	1F23
	(with hole,		1F50	1F16	1F43	1F33	1F29	1F62	1F22	1F40
		1F38	1F74	1F54	1F57	1F34	1F73	1F63	1F28	1F64
		1F45	1F101	1F100	1F61	1F47	1F96	1F72	1F83	1F77
		1F81	1F109	1F103	1F65	1F67	1F97	1F75	1F113	1F85
		1F99	1F118	1F105	1F82	1F92	1F107	1F78	1F115	
		1F112	1F119	1F106	1F84	1F108	1F114		1F121	
		1F123	1F120	1F124		1F117	1F116		1F122	1F10
19	Fatigue (w/o hole)	1F94	1F42	1F12	1F98	1F66	1F52		1F93	1F36
	Extra									1F37 1F10
	PHASE 1A									1F24
		AF27	AF1	AF38	AF3	AF5	AF25	AF64	AF63	AF45
		AF68	AF32	AF42	AF82	AF117	AF29	AF99	AF72	BF18
		AF137	AF48	AF84	BF229	BF206	AF70	BF191	AF75	BF22
		BF240	AF125	BF208	BF238	BF 266	BF221	BF258	AF124	BF23
		BF244	AF139	BR296	BF295	BF282	BF259	BF262	BF162	BF24
		BF260	BF264	BF298	BF302	BF291	BF279	BF276	BF288	BF24
	Spare	BF181	AF152	AF158	AF19	AF33	BF249	AF135	BF164	AF26
		BF261	BF175	BF278	AF151	BF176	BF265	BF233	AB232	AF47

TABLE 5 (continued)

PHASE 2

								United	United
	Belgium	France	Germany	Italy	Netherlands	Sweden	Turkey	Kingdom	States
	AF4	AF14	AF6	AF21	AF12	AF8	AF11	AF16	AF56
	AF15	AF17	AF30	AF69	AF24	AF9	AF23	AF22	AF71
	AF40	AF31	AF39	AF74	AF46	AF18	AF28	AF55	AF77
	AF51	AF41	AF44	AF87	AF62	AF49	AF34	AF58	AF78
	AF52	AF60	AF59	AF108	AF91	AF89	AF35	AF119	AF88
	AF61	AF80	AF118	AF116	AF101	AF96	AF79	AF133	AF112
	AF102	AF93	AF126	AF155	AF107	AF97	AF94	AF156	AF113
	AF104	AF110	AF129	BF171	AF127	AF145	AF98	BF166	AF114
	AF105	AF143	AF132	BF173	AF140	AF146	AF121	BF207	AF122
	AF109	AF144	BF177	BF182	AF141	AF165	AF154	BF211	AF136
	AF128	BF172	BF217	BF219	BF163	BF167	AF159	BF215	AF138
	BF192	BF174	BF257	BF253	BF189	BF185	BF222	BF220	BF223
	BF274	BF186	BF294	BF255	BF246	BF193	BF225	BF241	BF227
	BF286	BF188	BF300	BF293	BF283	BF210	BF237	BF248	BF228
	BF320	BF194	BF314	BF304	BF284	BF239	BF263	BF280	BF281
	BF325	BF272	BD319	BF311	BF326	BF299	BF315	BF303	BF305
Spares	AF50	AF13	AF73	AF36	AF106	BF226	AF130	AF160	AF43
•	AF53	AF148	AF150	AF90	BF184	BF254	AF153	BF195	AF111
	AF76	BF170	BF180	BF216	BF267	BF308	AF157	BF247	AF123
	BF292	BF245	BF218	BF230	BF268	BF310	AF161	BF269	BF179
	BF313	BF322	BF256	BF285	BF270	BF321	BF168	BF277	BF323

TABLE 6

LOW LOAD TRANSFER JOINT REVERSE DOGBONE SPECIMENS (MIL-STD-1312, TEST 21) IDENTIFICATION AND CHARACTERISTICS

PHASE 3

Specimen	Hole		Hole Di			Interference
Number	Quality	Fastener	#1*	#2*	#1	_#2
J41/J48	High Quality	K-Lobe (1)	.2472	.2469	.0042	.0045
J20/J42	High Quality	K-Lobe	.2471	.2470	0043	.0044
J8/J43	High Quality	K-Lobe	.2473	. 2472	0041	.0042
J2/J17	High Quality	K-Lobe	.2470	.2471	.0044	.0043
J45/J50	High Quality	K-Lobe	. 2469	.2469	.0045	.0045
J25/J35	High Quality	K-Lobe	.2471	.2470	.0043	.0044
	•					
J4/J33	Low Quality	K-Lobe	. 2628	. 2629	.0037	.0036
J18/J12	Low Quality	K-Lobe	. 2629	. 2629	.0036	.0036
J47/J10	Low Quality	K-Lobe	.2623	. 2626	.0042	.0039
J22/J26	Low Quality	K-Lobe	.2620	.2620	0045	.0045
J13/J53	Low Quality	K-Lobe	.2627	.2626	.0038	.0039
J2/J16	Low Quality	K-Lobe	.2621	. 2624	.0044	.0041
					<u>C1</u>	earance
J32/J51	Low Quality	VisuLok(2)	. 2631	.2633	.0016	.0018
J6/J40	Low Quality	VisuLok	.2630	. 2629	.0015	.0014
J5/J55	Low Quality	VisuLok	.2628	.2626	.0013	.0011
J7/J36	Low Quality	VisuLok	. 2629	. 2625	.0014	.0010
J24/J30	Low Quality	VisuLok	.2630	.2623	.0015	.0008
J44/J54	Low Quality	VisuLok	.2627	. 2635	,0012	.0020
-	• •					

^{*} Average of four Readings:

Two in Top Sheet (Max. and Min.)
Two in Bottom Sheet (Max. and Min.)

(1) K-Lobe Pin P/N KLB60V4M7, Ti-6Al-4V protruding head pin with AFN542-4 washer - torqued to 100 in.-lbs., set aside one-half hour and the re-torqued to 125 in.-lbs.

NOTE: Oversize K-Lobes were installed in low quality holes due to hole size requirements for the non-fatigue rated blind bolt system.

(2) Visu-Lok/Jo-Bolt, Monogram blind bolt, P/N PLT210-8-6

APPENDIX A



METCUT RESEARCH ASSOCIATES INC.

3980 Rosslyn Drive, Cincinnati, Ohio 45209 / Teletype: 810-461-2840 / Telephone: (513) 271-5100

The enclosed specimens are to be used on the AGARD SMP Critically Loaded Hole Technology Program per Revision C. The number of specimens enclosed is eight fatigue samples having a 1/4 in. center notch and 21 fatigue specimens having a 1/16 in. pilot hole in the center of the gage area. These specimens are to be tested per Paragraph 2.2.1 of Revision C.

The attached packing slip gives specimen identification and specimen numbers for each portion of the program. For the 1/4 in. center notch specimens, two are identified as spare samples. For the 1/16 in. pilot hole fatigue samples, there are five spares.

All testing results and format for reporting of data should be coordinated through Bob Urzi at Wright-Patterson Air Force Base. Any questions concerning the information generated should go to Mr. Urzi. Thank you for your cooperation.

Sincerely,

John B. Kohls, Supervisor Surface Technology

for

Robert B. Urzi
USAF Materials Laboratory
Systems Support Division, AFML/MXA
Wright-Patterson AFB, OH
USA, 45433

JBK:ph

Atch.



METCUT RESEARCH ASSOCIATES INC.

3980 Rosslyn Drive, Cincinnati, Ohio 45209 / Teletype: 810-461-2840 / Telephone: (513) 271-5100

Enclosed is the sealant to be used on the reverse dogbone Phase III specimens of the AGARD SMP critically loaded hole technology program. The specification and application instructions are also provided. It is important to the consistency of the program that each participant follow the directions completely for both mixing and application of the fay surface sealant.

Sincerely,

John B. Kohls, Supervisor Machinability Testing Metcut Research Associates Inc. for Robert Urzi, Air Force Materials Lab. Dayton, OH 45433

bЪ

APPENDIX B

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SURFACE PREPARATION AND APPLICATION OF PR-1431-G

SURFACE PREPARATION

- Clean surface with alkaline cleaner.
- Clean with oil free solvent immediately prior to application (do not use reclaimed solvent).

Use a progress procedure - clean a small area and wipe dry with clean cloth before solvent evaporates. Apply solvent to cloth not directly to part.

MIXING INSTRUCTIONS FOR STANDARD CONTAINERS

- Thoroughly stir the accelerator in its container until an even consistency is obtained.
- Mix the accelerator into the base compound until a uniform color is obtained. Uniformity of mixture will be complete when no gross dissimilarity exists.
- 3. The best mixing procedure is as follows:
 - (a) Thrust a spatula into the material at the 12 o'clock position
 - (b) Draw the spatula toward the 6 o'clock position with a slow three second stroke followed by a pause
 - (c) After completion of stroke, turn container 15-20 degrees, and begin next stroke. Repeat until uniformity is achieved.

- (d) Periodically run spatula around vertical inside wall of the container to remove any unmixed material. Also remove any unmixed material sticking to the spatula and return it to the material. This technique should take about 4-5 minutes.
- 4. It is mandatory that the temperature of the material be kept below 75°F (24C) during mixing.

Note: Proper mixing and correct proportion are extremely important for maximum result.

APPLICATION INSTRUCTION

PR-1431-G may be applied to faying surfaces by brush or roller. Before the expiration of the assembly life (20 hours), all work on the faying surface should be finished and all rivets or fasteners drawn tight.

To insure that no leak path exists through the sealant and that the faying surface is completely sealed, a small continuous bead of sealant should be squeezed out on both sides of the overlap when fasteners are drawn tight.

CURE TIME IN FAYING SURFACE

The PR-1431-G may be cured in eight days at 75°F (24C) or the cure may be accelerated by curing 24 hours at 75°F plus 24 hours at 130°F (55C).

APPENDIX C

CRITICALLY LOADED HOLE TECHNOLOGY PILOT PROGRAM

BATTELLE COLUMBUS LABORATORIES 505 KING AVENUE COLUMBUS, OHIO 43201

February, 1978

PHASE I REPORT FOR PERIOD APRIL, 1977, - JANUARY, 1978 METCUT RESEARCH ASSOCIATES, INC. PURCHASE ORDER NO. 62306

TABLE OF CONTENTS

	Page
INTRODUCTION	1
GENERATION OF THE FALSTAFF SPECTRUM	1
PROGRAM CONTROL	2
Pretest Checks	2
Bending Check	2
Static-Dynamic Loads Check	4
FALSTAFF Loads Check	4
TEST RESULTS	4
Fatigue Test Program	4
Tensile Test Program	4
SUMMARY AND CONCLUSIONS	8
APPENDIX I	
FATIGUE TEST DATA SHEETS	9
LIST OF FIGURES	
Plane 1 Process Control Couls	•
Figure 1. Program Control Cycle	3
Figure 2. Computer Command and Load Cell Signal Comparison for	5
·	,
Figure 3. Failure Surface of Specimen 1F64	7
Figure 4. Failure Surface of Specimen 1F10	7
LIST OF TABLES	
Table I. Fatigue Test Results	6
Mahila TT - Manakila Mark Darasika	•
a Portion of the Test on Specimen 1F40	

INTRODUCTION

A pilot program has been initiated by the AGARD SMP Subcommittee on Critically Loaded Hole Technology in an effort to promote a mutual confidence in fatigue test data generated by participating countries. The successful completion of the program will lead to a more uniform quality of fatigue testing and evaluation of critically loaded hole parameters among its participants. The objectives of the three-phase program are as follow:

- Phase I Generate baseline, open hole, fatigue data in order to examine laboratory-to-laboratory variations
- Phase II Reaffirm the exchangeability of baseline data and investigate the effect of hole quality on open hole fatigue specimens
- Phase III Conduct independent fatigue evaluations of various fatigue-improvement fasteners and exchange data.

Participants in the program included representatives from Belgium,
France, Germany, Italy, Netherlands, Sweden, United Kingdom, and the United
States. All specimens for the program are to be prepared by Metcut Research
Associates, Inc., from a single heat of 7050 material procured from Alcoa in the
form of 7050-T76 bare sheet, 0.196-inch (5 mm) thick. Battelle's Columbus
Laboratories (BCL) has been designated as the USA testing facility.

The report contained herein details the results of the Phase I effort.

GENERATION OF THE FALSTAFF SPECTRUM

In order to insure that all participants apply the same cyclic loads, each country was to test specimens under the FALSTAFF (Fighter Aircraft Loading STAndard For Fatigue). The BCL fatigue load control program was generated using the computer program detailed in the definitive description of the FALSTAFF spectrum, dated March 1976. The flight-by-flight load steps were generated on the BCL CDC 6400 main computer and stored on magnetic tape. The load steps were also printed out and checked carefully against the above-noted FALSTAFF description. Zero load was defined to be at load step 7.5269 of the 32 available load steps. A second magnetic tape was generated (compatible with the fatigue laboratory's Hewlett Packard 2100 computer) converting the load steps to percentages of full-scale load. This information was also stored on the laboratory computer disc unit.

PROGRAM CONTROL

This section describes the BCL system and equipment used to apply and control FALSTAFF program loads. In general, the HP 2100 computer provides load steps to a hybrid unit which generates a constant ramp rate function for the MTS 20,000-pound (88,960 N) closed-loop electrohydraulic fatigue machine. A null pacing unit makes a constant comparison of programmed load to load cell output and signals the hybrid unit when the programmed load has been reached, at which time the ramp direction is reversed and a new load is called from the computer. This procedure continues until a preprogrammed number of flights has been reached or until the test specimen fails. A graphic presentation of the program control cycle is presented in Figure 1. A secondary computer subroutine, STATS, makes it possible to determine the flight number, total number of cycles, and percent of a pass through the spectrum completed at the moment of questioning.

Pretest Checks

Prior to initiating the fatigue test program, a spare specimen (without a hole in the test section) was instrumented with two strain gages located near the specimen edge on each face of the specimen. The output of the four strain gages made it possible to determine specimen bending and buckling (if any existed) and to confirm that dynamic loads matched static calibration loads.

Bending Check

Strain gage data were obtained at incremental load steps for loads to an equivalent of 38 ksi (262 MPa) maximum and -19 ksi (131 MPa) minimum. Data were obtained for three loading cycles. The strain-load data were submitted to a linear regression analysis with resulting R² statistic values ranging from 1.000 to .9994. Strain values were computed for the load equivalent of 30 ksi (206.85 MPa) gross stress. Analysis of the strain values indicated that the maximum error due to specimen bending was 1.45 percent. Analysis of the compressive load data indicated that no buckling could be detected.

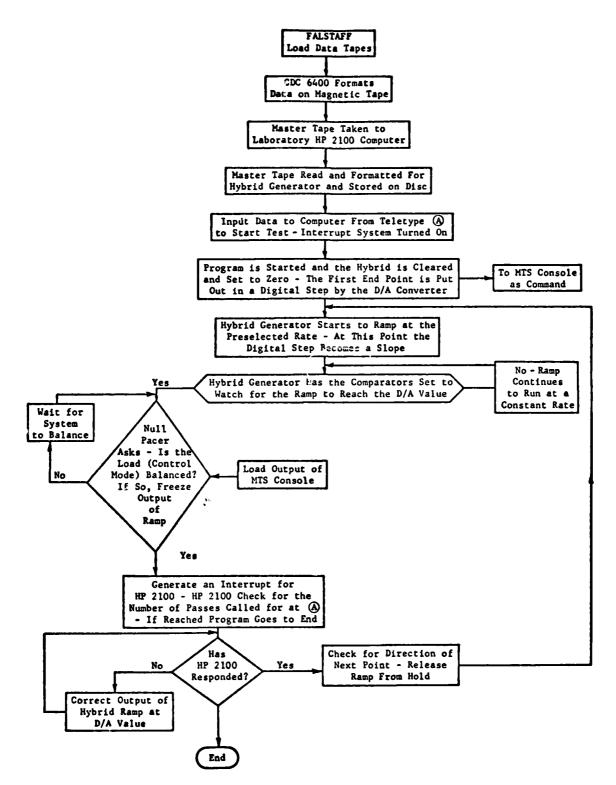


FIGURE 1. PROGRAM CONTROL CYCLE

Static-Dynamic Loads Check

Comparison of strain gage output and calibrated load cell output indicated a maximum axial load error of 1.33 percent at 38 ksi (262 MPa) static load. Application of cyclic loads at the same level provided the same strain outputs.

FALSTAFF Loads Check

The specimen was subjected to FALSTAFF loads cycling and ramp rate and MTS unit controls were adjusted so that fatigue machine load output matched the command signal (reference Figure 2). The controls were not changed during the rest of the test program and the mean cyclic rate was determined to be 10.5 Hz.

TEST RESULTS

Fatigue Test Program

Fatigue test specimens, as supplied by Metcut Research Associates, Inc., were selected at random. The initial specimen 1F37 was cycled at a reference (gross) stress level of FALSTAFF spectrum (Step 32) of 31 ksi (213.7 MPa) and testing was discontinued with no failure after 11,285 flights. Specimen 1F40 was cycled at a reference stress of 34 ksi (234.4 MPa) and failed at 9728 flights. The latter reference stress was then approved by the Project Monitor for use on the remaining five fatigue specimens. A summary of the fatigue test data is presented in Table I and detailed data sheets are included in Appendix I. Examples of typical failure surfaces are shown in Figures 3 and 4. In all cases, fatigue failures initiated at the open hole near the sheet midthickness.

Tensile Test Program

Tensile coupons provided by Metcut were tested in the Mechanical Test Laboratory on August 4, 1977. Tests were conducted in a Baldwin 60,000-pound-(266,890 N) capacity Universal test machine. Room temperature was 69 degrees F (21°C) and the relative humidity was 60 percent. The loading rate was controlled at 100 ksi/min (689.5 MPa/min). The results of the tensile tests are presented in Table II.

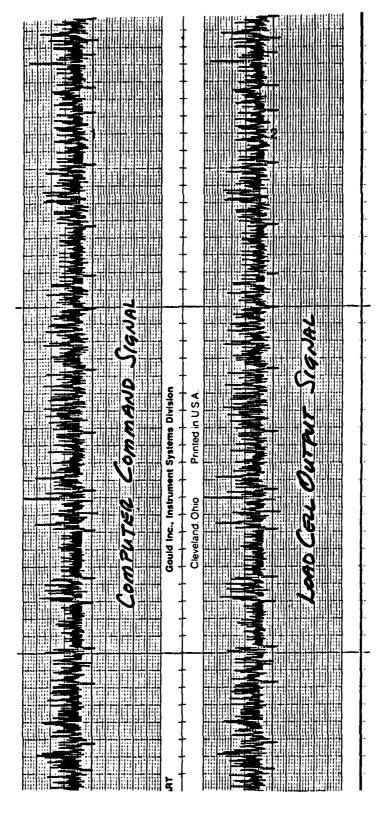


FIGURE 2. COMPUTER COMMAND AND LOAD CELL SIGNAL COMPARISON FOR A PORTION OF THE TEST ON SPECIMEN 1F40

TABLE I. FATIGUE TEST RESULTS*

Specimen Number	Flights to Initial Crack	Initial Crack Size, inch (mm)	Flights to Failure
1F40	9128	0.05 (1.27)	9728
1F23			9373
1F64		••	8824
1F77	9297	0.03 (0.76)	9572
1F85	9835	0.02 (0.51)	10929
1F10			8364
Mean Life			9465
Standard D	eviation		878

^{*} FALSTAFF reference stress - 34 ksi (234.4 MPa).

TABLE II. TENSILE TEST RESULTS

Specimen Number	Yield Strength, ksi (MPa)	Ultimate Strength, ksi (MPa)	Elongation, percent (2-inch gage)
1T24	80.79 (557.0)	84.40 (581.9)	11.5
1 T 30	80.60 (555.7)	84.34 (581.5)	11.5
1T19	80.22 (553.1)	84.15 (580.2)	11.0
Average	80.54 (555.3)	84.30 (581.2)	11.33
Standard Deviation	.29	.13	.29

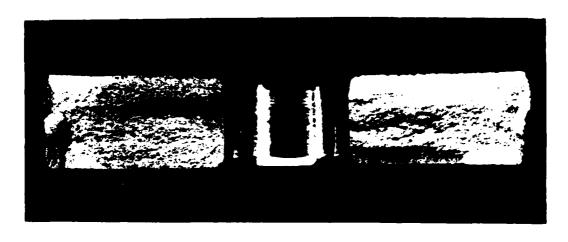


FIGURE 3. FAILURE SURFACE OF SPECIMEN 1F64

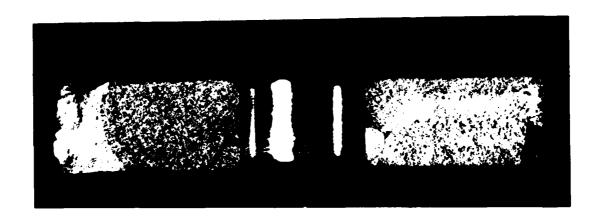


FIGURE 4. FAILURE SURFACE OF SPECIMEN 1F10

SUMMARY AND CONCLUSIONS

Because of the care taken to insure that the FALSTAFF spectrum had been carefully reproduced and continuous checks made during the set-up procedure, it is believed that the fatigue data are truly representative of the lives that can be expected for this test condition. This is confirmed by the low standard deviation for the data (well within normally obtained values). It is expected that the Phase II results will yield results of similar quality. As a result of this phase, all participating nations should be encouraged to continue with Phase II of the program.

APPENDIX I

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

1.	Date of Test: Start 7/12/77 End 7-14-77
2.	Manufacture/Model of Fatigue Test Machine: MTS 10 KIP
3.	Test Temperature: 68 % (20 20 4 9C)
4.	Relative Humidity: 56 (%)
5.	Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
	34 kei (234,4 MPa)
6.	Specimen Identification: 1-140
7.	Specimen Bending at Minimum Load: NONE 2
8.	Specimen Bending at RMS Mean Load: 1.45 %
9.	RMS Mean Cyclic Frequency: 10:5 Hz
10.	Number of Flights to Initial Visible Crack: 9/28 Flights
11.	Size of Initial Visible Crack: 105 (Poyt in. (1.27 mm)
12.	Number of Flights to Catastrophic Failure: 9727 Flights
13.	Patigue-Crack-Initiation Site: NHOLE AT MID THICKNESS
	- BOTH SIDES
	Sketch
14.	Description of Abnormalities:
15.	Description of Buckling Restraint (If Used): NONE

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

1.	Date of Test: Start 7-14-77	End _	1/1	6/77
	Manufacture/Model of Fatigue Test Machine:		•	•
3.	Test Temperature: 47 or	· (20	•c)
	Relative Humidity: 55 (%)			
5.	Reference (Gross) Stress Level of FALSTAFF Spe	ectrum (Step 32)	
	3Uksi (_23	34.4	MPa)
6.	Specimen Identification: 1 F 2 3		·	
7.	Specimen Bending at Minimum Load: NoNE	· %		
8.	Specimen Bending at RMS Mean Load: 1.45	<u> </u>		
9.	RMS Mean Cyclic Frequency:	Hz		
lo.	Number of Flights to Initial Visible Crack:			Flights
11.	Size of Initial Visible Crack:	1	a. (
12.	Number of Flights to Catastrophic Failure:	9	373	Flights
13.	Fatigue-Crack-Initiation Site: IN HOLE	NEAR	mid	THICKNESS
				S kerch
4.	Description of Abnormalities:			
5.	Description of Buckling Restraint (If Used);			

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

1.	Date of Test: Start	•
2.	Hanufacture/Model of Fatigue Test Machine: MTS 20 KIP	
3.	Test Temperature: 69 or (20	°C)
4.	Relative Humidity: (%)	
5.	Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)	
	34 kei (234,4 MPa)	
6.	Specimen Identification: 1F64	
7.	Specimen Bending at Minimum Load: New 2	
8.	Specimen Bending at RMS Mean Load: 1.45 %	
9.	RMS Mean Cyclic Frequency: 10.5 Hz	
	Number of Flights to Initial Visible Crack: Flight	
11.	Size of Initial Visible Crack:in. (m)
	Number of Flights to Catastrophic Failure: 8814 Flight	
	Patigue-Crack-Initiation Site: NHOLE NEAR MID THICKNES	
	Sketc	h
14.	Description of Abnormalities:	
15.	Description of Buckling Restraint (If Used): NONE	

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

1.	Date of Test: Start 7/16/77 End 7/23/77
2.	Manufacture/Model of Fatigue Test Machine: M.T.S. 20 KJP
3.	Test Temperature: 68° or (20°C)
	Relative Humidity: (%)
5.	Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
	34 ket (234,4 HPa)
6.	Specimen Identification: 1 F 77
7.	Specimen Bending at Minimum Load: NONE %
8.	Specimen Bending at RMS Mean Load: 1.45 %
9.	RMS Mean Cyclic Frequency: 10.5 Hz
0.	Number of Flights to Initial Visible Crack: 9297 Flights
11.	Size of Initial Visible Crack: 0.03 in. (0.76 mm)
2.	Number of Flights to Catastrophic Failure: 9572 Flights
3.	Fatigue-Crack-Initiation Site: IN HOLE WEAR MID THICKNETS
	Sketch
4.	Description of Abnormalities:
5.	Description of Buckling Restraint (If Used): NONE

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

1.	Date of Test: Start 7/27/77 End 7/1.9/77
2.	Date of Test: Start 7/27/77 End 7/29/77 Manufacture/Model of Fatigue Test Machine: MTS 20 KM2
3.	Test Temperature: 680 or (20 °C)
4.	Relative Humidity: (%)
5.	Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
	3 4 ket (234,4 MPa)
6.	34 kmi (234,4 MPa) Specimen Identification: 1F 85
7.	Specimen Bending at Minimum Load: NoNE %
8.	Specimen Bending at RMS Mean Load: 1.45 %
9.	RMS Mean Cyclic Frequency: 10.5 Hz
10.	Number of Flights to Initial Visible Crack: 9835 Flights
	Size of Initial Visible Crack: DJO in. (0.51 mm)
l2.	Number of Flights to Catastrophic Failure: 10929 Flights
13.	Number of Flights to Catastrophic Failure: 10929 Flights Fatigue-Crack-Initiation Site: 10 Hole NEAR MIDTHICKNESS
	Sketch
4.	Description of Abnormalities:
.5.	Description of Buckling Rescraint (If Used): NONE

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

1.	Date of Test: Start 7-30-77 End 8-1-77	
2.		
3.	Test Temperature: 68 or (20	°C)
4.		
5.	Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)	
	34 kei (234,4 MPa)	
6.	Specimen Identification: 1-F-10	
7.	Specimen Bending at Minimum Load: None %	
8.	Specimen Bending at RMS Mean Load: 1.45 %	
9.		
10.	Number of Flights to Initial Visible Crack: Flight	. s
11.	Size of Initial Visible Crack:in. (m)
	Number of Flights to Catastrophic Failure: 8,364 Plight	
13.	Patigue-Crack-Initiation Site: LU HULE NEAR MIDTHICKNES	
	Sketo	h
14.	Description of Abnormalities:	
15.	Description of Buckling Restraint (If Used): Now E	
		_

APPENDIX D

CRITICALLY LOADED HOLE TECHNOLOGY PILOT PROGRAM

PHASE II REPORT FOR PERIOD APRIL 1978 - AUGUST 1978

BATTELLE COLUMBUS LABORATORIES 505 KING AVENUE COLUMBUS, OHIO 43201

August 1978

METCUT RESEARCH ASSOCIATES, INC. PURCHASE ORDER NO. 63654

INTRODUCTION

A pilot program has been initiated by the AGARD SMP Subcommittee on Critically Loaded Hole Technology in an effort to promote a mutual confidence in fatigue test data generated by participating countries. The successful completion of the program will lead to a more uniform quality of fatigue testing and evaluation of critically loaded hole parameters among its participants. The objectives of the three-phase program are as follow:

- Phase I Generate baseline, open hole, fatigue data in order to examine laboratory-to-laboratory variations
- Phase II Reaffirm the exchangeability of baseline data and investigate the effect of hole quality on open hole fatigue specimens
- Phase III Conduct independent fatigue evaluations of various fatigue-improvement fasteners and exchange data.

Participants in the program included representatives from Belgium, France, Germany, Italy, Netherlands, Sweden, United Kingdom, and the United States. All specimens for the program are to be prepared by Metcut Research Associates, Inc., from a single heat of 7050 material procured from Alcoa in the form of 7050-T76 bare sheet, 0.196-inch (5 mm) thick. Battelle's Columbus Laboratories (BCL) has been designated as the USA testing facility.

The report contained herein details the results of the Phase II effort.

GENERATION OF THE FALSTAFF SPECTRUM

In order to insure that all participants apply the same cyclic loads, each country was to test specimens under the FALSTAFF (Fighter Aircraft Loading STAndard For Fatigue). The BCL fatigue load control program was generated using the computer program detailed in the definitive description of the FALSTAFF spectrum, dated March 1976. The details of the BCL load control program generation were presented in the Phase I report dated February 1978.

PROGRAM CONTROL

This section describes the BCL system and equipment used to apply and control FALSTAFF program loads. In general, the HP 2100 computer provides load steps to a hybrid unit which generates a constant ramp rate function for the MTS 20,000-pound (88,960 N) closed-loop electrohydraulic fatigue machine. A null pacing unit makes a constant comparison of programmed load-to-load cell output and signals the hybrid unit when the programmed load has been reached, at which time the ramp direction is reversed and a new load is called from the computer. This procedure continues until a preprogrammed number of flights has been reached or until the test specimen fails. A graphic presentation of the program control cycle is presented in Figure 1. A secondary computer subroutine, STATS, makes it possible to determine the flight number, total number of cycles, and percent of a pass through the spectrum completed at the moment of questioning.

Pretest Checks

Prior to initiating the fatigue test program, pretest checks were made (as in Phase I) using the Phase I spare specimen (without a hole in the test section) instrumented with two strain gages located near the specimen edge on each face of the specimen. The output of the four strain gages made it possible to determine specimen bending and buckling (if any existed) and to confirm that dynamic loads matched static calibration loads.

Bending Check

Strain gage data were obtained at incremental load steps for loads to an equivalent of 38 ksi (262 MPa) maximum and -19 ksi (131 MPa) minimum. Data were obtained for three loading cycles. The strain-load data were submitted to a linear regression analysis with resulting R² statistic values ranging from 1.000 to .9994. Strain values were computed for the load equivalent of 30 ksi (206.85 MPa) gross stress. Analysis of the strain values indicated that the maximum error due to specimen bending was 2.53 percent. Analysis of the compressive load data indicated that no buckling could be detected.

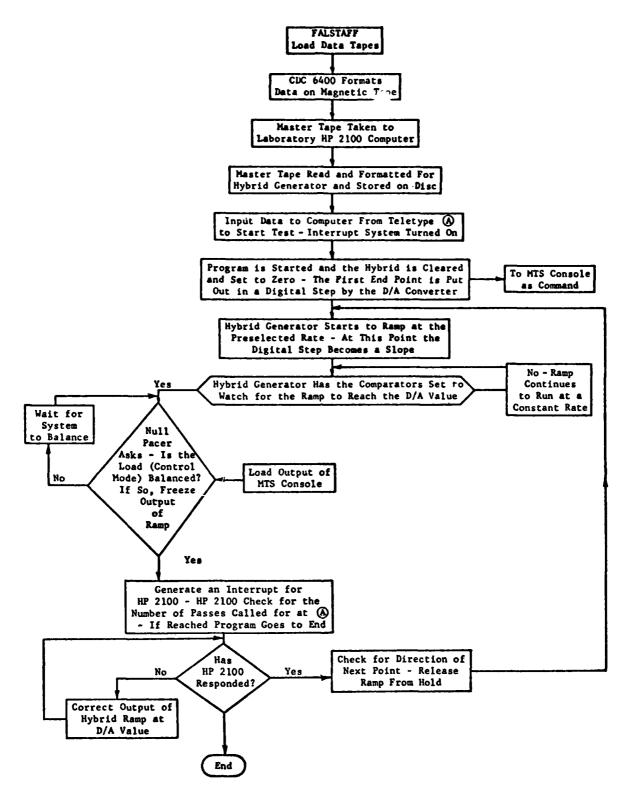


FIGURE 1. PROGRAM CONTROL CYCLE

Static-Dynamic_Loads Check

Comparison of strain gage output and calibrated load cell output indicated a maximum axial load error of 2.30 percent at 38 ksi (262 MPa) static load. Application of cyclic loads at the same level provided the same strain outputs at frequencies of 1, 5, and 10 Hz.

FALSTAFF Loads Check

The specimen was subjected to FALSTAFF loads cycling and ramp rate and MTS unit controls were adjusted so that fatigue machine load output matched the command signal (reference Figure 2). In addition, records were made of computer command signal versus dummy specimen strain level (reference Figure 3) and command signal versus load cell output over expanded time scale (reference Figure 4). Note that Figure 4 shows the time lag (0.0008 to 0.0020 seconds) required to extract the next load command from the computer. The controls were not changed during the rest of the test program and the mean cyclic rate was determined to be 10.5 Hz.

TEST RESULTS

Fatigue Test Program

Fatigue test specimens, as supplied by Metcut Research Associates, Inc., were selected at random from all three specimen types (Phase I Report, high and low quality holes). All specimens were cycled at a reference stress of 34 ksi (234.4 MPa). A summary of the fatigue test data is presented in Table I and detailed data sheets are included in Appendix I. Macrographs of failure surfaces are shown in Appendix II.

NOTE: The data for the High Quality Hole Specimen BF-179, which failed at 15,176 flights, is not tabulated because it was determined that the programmed reference load was set approximately 20 percent of the required level of 34 ksi (234.4 MPa).

TABLE I. FATIGUE TEST RESULTS*

pecimen Nur	mber Flig	hts to Failure
	PHASE I REPEAT	
AF-26		8.172
BF-242		6,680
BF-235		6,359
BF-224		7,729
AF- 45		6,831
AF-47		6,831
	Mean Lif	e 7,100
	Standard Deviation	n 695
	HIGH-QUALITY HOLE	<u>s</u>
BF-227		8,129
AF-122		8,392
BF-281		9,572
AF-78		5,231
AF-136		10,324
	Mean Lif	e 8,330
	Standard Deviatio	n 1,947
	LOW-QUALITY HOLE	<u>s</u>
BF-305		9,329
BF-323		5,372
BF-228		6,631
AF-123		6,224
AF-88		5,372
AF-43		7,431
AF-138		6,831
AF-114		4,972
BF-223		6,877
AF-112		5,431
	Mean Lif	e 6,447
	Standard Deviatio	n 1,300

^{*} FALSTAFF reference stress - 34 ksi (234.4 MPa)

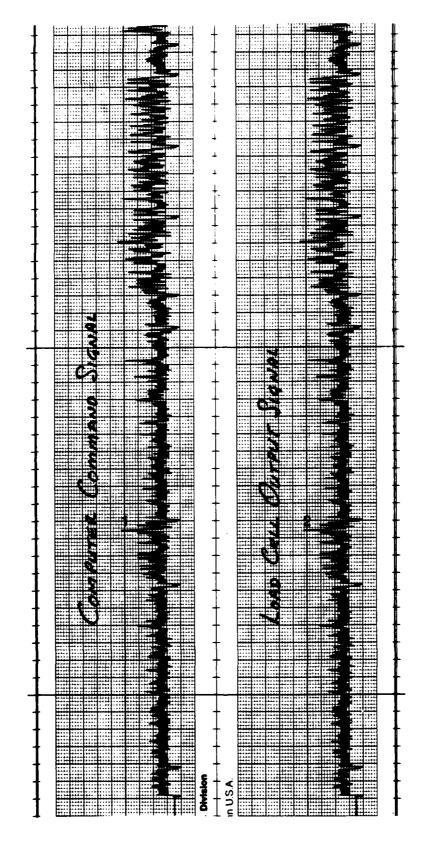


FIGURE 2. COMPUTER COMMAND AND LOAD CELL SIGNAL COMPARISON FOR A PORTION OF THE TEST ON SPECIMEN AF-26

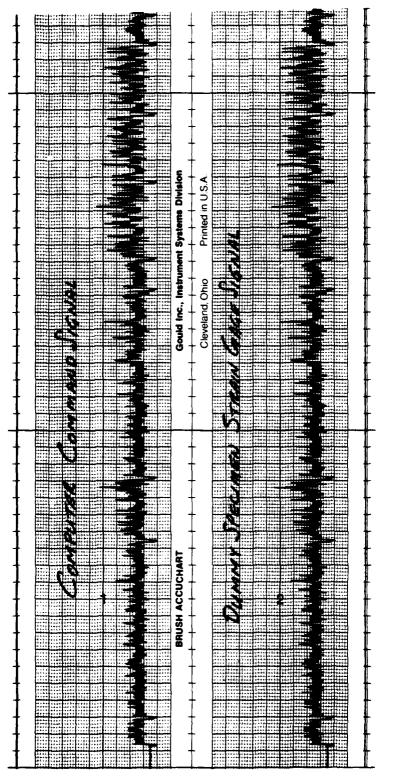


FIGURE 3. COMPUTER COMMAND AND DUMMY SPECIMEN STRAIN GAGE SIGNAL FOR A PORTION OF THE FALSTAFF SPECTRUM

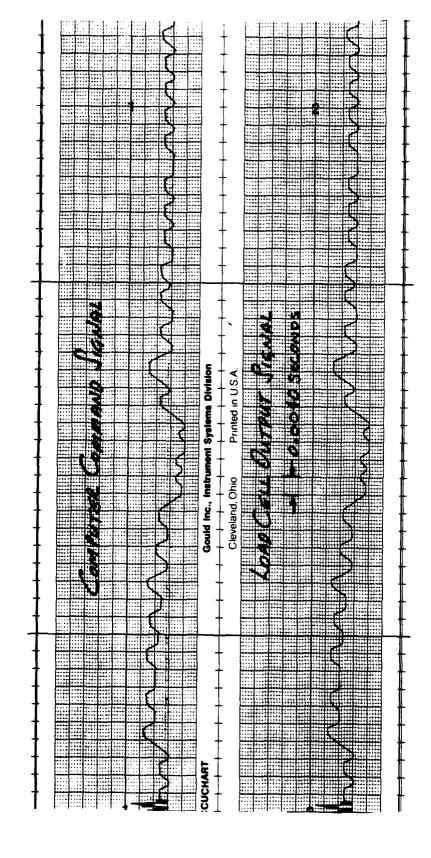


FIGURE 4. EXPANDED TIME SCALE COMPARISON OF COMPUTER COMMAND AND LOAD CELL OUTPUT SIGNALS FOR A PORTION OF THE FALSTAFF SPECTRUM

APPENDIX I

DETAILED DATA SHEETS

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES STRUCTURAL MATERIALS AND TRIBOLOGY SECTION STRUCTURAL FATIGUE LABORATORY 1. Date of Test: Start 6-8-78 2. Manufacture/Model of Fatigue Test Machine: MTS 20K1P 3. Test Temperature: ______OP OC) 4. Relative Humidity: <u>56</u> (%) 5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32) (234.4 ksi____ 6. Specimen Identification: AF-Z6 7. Specimen Bending at Minimum Load: ~~ べつん こ な 8. Specimen Bending at RMS Mean Load: 2.53 % 9. RMS Mean Cyclic Frequency: 10.5 Hz 10. Number of Flights to Initial Visible Crack: 472 N.A. Flights 12. Number of Flights to Catastrophic Failure: 8172 Flights 13. Fatigue-Crack-Initiation Site: SEE PHOTO Sketch 14. Description of Abnormalities: NONE 15. Description of Buckling Restraint (If Used):

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

1.	Date of Test: Start 6-13-75	En	a <u>/</u>	14	-28	
2.	Manufacture/Model of Fatigue Test Machine:	411	7-5	200	111	
3.	Test Temperature: //- 5 op	(. <u>.</u>	20		C)
4.	Relative Humidity: 55 (%)					
5.	Reference (Gross) Stress Level of FALSTAFF Sp	pectru	m (Step	32)		
		54	.4	MPa)		
6.	Specimen Identification: 13 F 32	(S				
7.	Specimen Bending at Minimum Load: 116 r	., €°.	7.			
8.	Specimen Bending at RMS Mean Load: 25	<u>- ゴ</u>	7.			
9.	RMS Mean Cyclic Frequency:		Hz			
10.	Number of Flights to Initial Visible Crack:		110	<i>t</i>	Flights	5
11.	Size of Initial Visible Crack: ////		_ in.			nn)
12.	Number of Flights to Catastrophic Failure:		.77	7 · j	Flights	5
13.	Fatigue-Crack-Initiation Site:					
						_
	see Photo				Sketcl	1
14.	Description of Abnormalities: NONE		·	,		
15.	Description of Buckling Restraint (If Used):					

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

Date of Test: Start	3-14-76		End	15-16	<i>i</i> -
Manufacture/Model of F	atigue Test Machi	ne: <u>:</u>	155	211	(11)
Test Temperature:	68	op _	(°C)
Relative Humidity:					
Reference (Gross) Stre	ss Level of FALST	AFF Spec	trum (Step	32)	
-34	ksi (7.34	1.4	MPa)	
Specimen Identification	n: BF 3	27			
Specimen Bending at Mi	nimum Load:	lome.	%		
Specimen Bending at RM	S Mean Load:	153	%		
RMS Mean Cyclic Freque	ncy:	. 7 .	Hz		
Number of Flights to I	nitial Visible Cr	ack;	110		Flights
Size of Initial Visibl	e Crack:	17)	in.	(mm)
Number of Flights to C	atastrophic Failu	re:	8174		Flights
Fatigue-Crack-Initiati	on Site:				
		 _			
بے دینے چانے	Photo				Sketch
Description of Abnorma	lities: <u>N</u>	NE			
Description of Buckling	g Restraint (If U	sed): _			

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

1.	Date of Test: Start _	6-15-7	<u>Ś</u> Er	nd <i>C</i>	1 16	18	
2.	Manufacture/Model of Fa	atigue Test Machi	ne: <u>///</u>	75	cock.	111	
3.	Test Temperature:						
4.	Relative Humidity:	5 5	_ (%)				
5.	Reference (Gross) Street	ss Level of FALST	AFF Spectru	ım (Step	32)		
		ksi	<u> </u>	1.4	MPa)		
6.	Specimen Identification						
7.	Specimen Bending at Min	nimum Load:	line	7.			
8.	Specimen Bending at RMS	Mean Load:	253	7.			
9.	RMS Mean Cyclic Frequen	ncy:	<u>;</u>	Hz			
10.	Number of Flights to In	nitial Visible Cr	ack:	11		Flight	s
11.	Size of Initial Visible	Crack:	1,7	_in.			mm)
	Number of Flights to Ca						
13.	Fatigue-Crack-Initiation	on Site:	·				
							
		ec Phic	40			Sketo	h
14.	Description of Abnormal	ities:	100			······································	
15.	Description of Buckling	Restraint (If U	sed):	·			

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TÉCHNOLOGY PROGRAM

Date of Test: Start	<u> </u>	78	End	6-17-	75
Manufacture/Model of Fa	itigue Test M	achine:	111	TS 20	KID
Test Temperature:	6.8	oğ	'	20	o(
Relative Humidity:	55	(%)			
Reference (Gross) Stres	s Level of P	ALSTAFF Spe	ctrum (St	ep 32)	
34	ksi	(34.4	MPa)	
Specimen Identification	ı:	0 F-68	<u>:-</u>		
Specimen Bending at Min	imum Load:	Heir.	<u>* </u>		
Specimen Bending at RMS	Mean Load:	ِّد ? <u>'</u> ۽	3 7		
RMS Mean Cyclic Frequen	cy:	10.5	Hz		
Number of Flights to In				11/1	Flights
Size of Initial Visible					
Number of Flights to Ca	tastrophic F	ailure:	5.3	72	Flights
Fatigue-Crack-Initiatio	n Site:				-
~~	= 12h	110			Sketch
	,				
Description of Abnormal	itiaa.	dun	į.		
nescribilion or wonormar	11168:		···		
December of Burkley	Page de la			 	
Description of Buckling	Kestraint (ri need):			

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

•	Date of Test: Start 6-19-78 End 6-76-	18
٠	Manufacture/Model of Fatigue Test Machine: 2015 701	110
•	Test Temperature: OF (2.0	•c)
•	Relative Humidity: 55 (%)	
•	Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)	
	ksi (
•	Specimen Identification: 115-126	
•	Specimen Bending at Minimum Load: 1/01) 6. 7	
•	Specimen Bending at RMS Mean Load:	
•	RMS Mean Cyclic Frequency: Rz	
•	Number of Flights to Initial Visible Crack:	Flights
•	Size of Initial Visible Crack:in. (
•	Number of Flights to Catastrophic Failure: 5392	Flights
	Fatigue-Crack-Initiation Site:	·
	See Photo	Sketch
•	Description of Abnormalities:	
•	Description of Buckling Restraint (If Used):	

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

1.	Date of Test: Start 6-21-78 End 6-22-7.	9
2.	Manufacture/Model of Fatigue Test Machine: MTS - ZC KIP	
3.	Test Temperature: 68 of (20	•c)
4.	Relative Humidity: 5-5 (%)	
5.	Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)	
	34 ksi (23414 MPa)	
6.	Specimen Identification: 8F-228	
7.	Specimen Bending at Minimum Load: NINE 2	
8.	Specimen Bending at RMS Mean Load: 2.53 %	
9.	RMS Mean Cyclic Frequency: 10.5 Hz	
10.	A	Flights
11.	Size of Initial Visible Crack: NA in. (man)
12.	Number of Flights to Catastrophic Failure: 6631	Flights
13.	Fatigue-Crack-Initiation Site:	
	SEE PHOTO	Sketch
14.	Description of Abnormalities: NONE	
15.	Description of Buckling Restraint (If Used):	

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

1	Date of Test: Start 6-22-26 End 6-25-	·) 8
1	Manufacture/Model of Fatigue Test Machine:	(11)
•	Test Temperature: OS or (SC	°c
1	Relative Humidity: (%)	
1	Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)	
	54 ksi (<u>734-4 MPa)</u>	
:	Specimen Identification: 127-123	
:	Specimen Bending at Minimum Load: 1/6/16. 7	
:	Specimen Bending at RMS Mean Load:	
1	RMS Mean Cyclic Frequency: Hz	
	Number of Flights to Initial Visible Crack:	_ Flights
:	Size of Initial Visible Crack: 1/1- in. (m n
1	Number of Flights to Catastrophic Failure:	_ Flights
1	Fatigue-Crack-Initiation Site:	
_		
	See Placto	Sketch
1	Description of Abnormalities:	
1	Description of Buckling Restraint (If Used):	

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

	<u></u>	End 6-2	1-18
Manufacture/Model of Fatigue Test P	Machine:	1178 3	CKIP
Test Temperature:			
Relative Humidity:			
Reference (Gross) Stress Level of E	ALSTAFF Spect	trum (Step 32)	
ksiksi	(34-4 MP	a)
Specimen Identification:	BF-30	17	
Specimen Bending at Minimum Load:			
Specimen Bending at RMS Mean Load:	27.5	<u> </u>	
RMS Mean Cyclic Frequency:	18.5	Hz	
Number of Flights to Initial Visible			Flights
Size of Initial Visible Crack:	1.11	in. (tim
Number of Flights to Catastrophic I			
Patigue-Crack-Initiation Site:			
			
-See	MAET	. .	0 1 1
			Sketch
Description of Abnormalities:	lene	£.	

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

1.	Date of Test: Start 6-27-78 End 6-28-7	8
2.	Manufacture/Model of Fatigue Test Machine: 30 KIP MTS	
3.	Test Temperature: 68 of (20	°C)
4.	Relative Humidity: 55 (%)	
5.	Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)	
	34 ksi (234.4 MPa)	
6.	Specimen Identification: AF-43	
7.	Specimen Bending at Minimum Load:7	
8.	Specimen Bending at RMS Mean Load: 2.53 7	
9.	RMS Mean Cyclic Frequency: 1015 Hz	
10.		Flights
11.	Size of Initial Visible Crack: NA in. (
12.	Number of Flights to Catastrophic Failure: 7431	Flights
13.	Fatigue-Crack-Initiation Site:	
	SEE PHOTO	Sketch
14.	Description of Abnormalities: NONE	
L5.	Description of Buckling Restraint (If Used):	

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

1.	Date of Test: Start End
2.	Manufacture/Model of Fatigue Test Machine:
3.	Test Temperature: OF (CC OC
4.	Relative Humidity: (%)
5.	Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
	ksi (
6.	Specimen Identification: 177-342
7.	Specimen Bending at Minimum Load: 1/1/26 %
8.	Specimen Bending at RMS Mean Load: 7
9.	RMS Mean Cyclic Frequency: Hz
10.	Number of Flights to Initial Visible Crack: (11) Flights
11.	Size of Initial Visible Crack:in. (mm
12.	Number of Flights to Catastrophic Failure: 665 Flights
13.	Patigue-Crack-Initiation Site:
	See Phato Sketch
14.	Description of Abnormalities:
15.	Description of Buckling Restraint (If Used):

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

1.	Date of Test: Start 6-38-28 End 27-1-	78
2.	Manufacture/Model of Fatigue Test Machine:	
3.	Test Temperature: OF (
4.	Relative Humidity: (%)	
5.	Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)	
6.	Specimen Identification: 1) 7-13 &	
7.	Specimen Bending at Minimum Load:	
8.	Specimen Bending at RMS Mean Load:	
9.	RMS Mean Cyclic Frequency: Hz	
10.	Number of Flights to Initial Visible Crack:	Flights
11.	Size of Initial Visible Crack: 1/17 in. (mn)
12.	Number of Flights to Catastrophic Failure: 6.53/	Flights
13.	Fatigue-Crack-Initiation Site:	
	see Photo	Sketch
14.	Description of Abnormalities: //c,,)C	
15.	Description of Buckling Restraint (If Used):	

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

Date of Test: Start 7-1-78. End 7-2-78	
Manufacture/Model of Fatigue Test Machine:	111
Test Temperature: & (ZC	°C)
Relative Humidity: 55 (%)	
Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)	
3'4 kei (234.4 MPa)	
Specimen Bending at Minimum Load: 2/20 2 %	
Specimen Bending at RMS Mean Load:	
RMS Mean Cyclic Frequency:	
Number of Flights to Initial Visible Crack:	Flights
Size of Initial Visible Crack: //- in. (
Number of Flights to Catastrophic Failure: 5.23/	Flights
Fatigue-Crack-Initiation Site:	
San Phile	
	Sketch
Description of Abnormalities:	
	
Description of Buckling Restraint (If Head).	
sescribaton of shearing weathering for oseal.	
	Manufacture/Model of Fatigue Test Machine: M75 30 K Test Temperature: E OF (2C Relative Humidity: 55 (%) Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32) Specimen Identification: 234-4 MPa) Specimen Bending at Minimum Load: Messer % Specimen Bending at RMS Mean Load: 53 % RMS Mean Cyclic Frequency: Hz Number of Flights to Initial Visible Crack: Messer Machine: 5-3/ Number of Flights to Catastrophic Failure: 5-3/

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

Date of Test: Start	7-2-78		End	-3-78	·
Manufacture/Model of Fa	tigue Test Mac	hine:	1175	. 70	Kill.)
Test Temperature:			(ي حن	°c
Relative Humidity:	<u></u>	(%)			
Reference (Gross) Stres	s Level of FAL	STAFF Spec	trum (Ste	p 32)	
574	ksi	(27	34.4	MPa)	
Specimen Identification	·:	2=-11	4		
Specimen Bending at Min	imum Load:	Mont	2		
Specimen Bending at RMS	Mean Load:	27.5	<u> </u>		
RMS Mean Cyclic Frequen	icy:	10.5	Hz		
Number of Flights to In	itial Visible	Crack: _	1.10	1	Flights
Size of Initial Visible	Crack:	, 1 ++	in.	(a a
Number of Flights to Ca	tastrophic Fai	lure:	497	. Z.	Flights
Fatigue-Crack-Initiation	n Site:				
	See K	boto			
.*		,,,,,,			Sketch
Description of Abnormal	ities:	dene	·.		
•					
Description of Buckling	Restraint (If	Used):			
Annay bearing as annury 1.8	,	/-			

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

1.	Date of Test: Start 7-3-78	End 7-4-78
2.	Manufacture/Model of Fatigue Test Machine:	1418-30211
3.	Test Temperature: 6 C op	(°C)
	Relative Humidity: 55 (%)	
5.	Reference (Gross) Stress Level of FALSTAFF Spec	trum (Step 32)
	34ksi (<u> </u>
6.	Specimen Identification: ///F-/	? C:
7.	Specimen Bending at Minimum Load: 1600+	%
8.	Specimen Bending at RMS Mean Load:	<u> </u>
9.	RMS Mean Cyclic Frequency:	Hz
10.	Number of Flights to Initial Visible Crack:	
11.	Size of Initial Visible Crack: ///-)	in. (
12.		
13.	Fatigue-Crack-Initiation Site:	
	See Photo	Sketch
14.	Description of Abnormalities: //ene	
15.	Description of Buckling Restraint (If Used):	

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

Date of Test: Start 7-5-76	End	17-6	78	
Manufacture/Model of Fatigue Test Machine:		1-5	T. 2 17.71	,)
Test Temperature:	TF (3.6	°C)
Relative Humidity:	(%)			
Reference (Gross) Stress Level of FALSTAFF	Spectrum	(Step 32)		
5-/ksi (234	. / MPa)		
Specimen Identification: /5 /	- 22	3		
Specimen Bending at Minimum Load:/o	/) e' 7	1		
Specimen Bending at RMS Mean Load:	5-3 %	ı		
RMS Mean Cyclic Frequency: /c.:	<u> </u>	z		
Number of Flights to Initial Visible Crack			Fligh	ts
Size of Initial Visible Crack:	<u>,,)</u>	in. (mm)
Number of Flights to Catastrophic Failure:	<u>_</u>	1577	Fligh	ts
Fatigue-Crack-Initiation Site:	 			
See Pho	10		Sket	ch
Description of Abnormalities:	· · · · · · · · · · · · · · · · · · ·			
Description of Buckling Restraint (If Used):			

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

Date of Test: Start 2-2-75	End	7-6.0	کو د کو د
Test Temperature:	(°C)
Relative Humidity: 55 (%)			
Reference (Gross) Stress Level of FALSTAFF Speci		-	
Specimen Identification:	7		
Specimen Bending at Minimum Load: 2/2/17	%		
Specimen Bending at RMS Mean Load:	_ %		
RMS Mean Cyclic Frequency:	Hz		
Number of Flights to Initial Visible Crack:	1.)	_ Flights
Size of Initial Visible Crack:	in.	<u></u>	
Number of Flights to Catastrophic Failure:	• و کي	5 9	_ Flights
Fatigue-Crack-Initiation Site:		,	
Sec Photo			Sketch
Description of Abnormalities:			
Description of Buckling Restraint (If Used):			
	·		
	Manufacture/Model of Fatigue Test Machine: Test Temperature: George Relative Humidity: Seference (Gross) Stress Level of FALSTAFF Spectory ksi Specimen Identification: Specimen Bending at Minimum Load: Specimen Bending at RMS Mean Load: RMS Mean Cyclic Frequency: Number of Flights to Initial Visible Crack: Size of Initial Visible Crack: Number of Flights to Catastrophic Failure: Fatigue-Crack-Initiation Site:	Manufacture/Model of Fatigue Test Machine: Test Temperature: Relative Humidity: Seference (Gross) Stress Level of FALSTAFF Spectrum (Sternard Reference (Gross) Stress Level of FALSTAF	Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32) Ksi

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

Date of Test: Start		٠,٠,٠,		End	11-7		
Manufacture/Model of Fa	tigue Tes	t Machin	e;	1475.	. 361	(11)	
Test Temperature:		مع ي	or	(20		°C)
Relative Humidity:		5	(%)				
Reference (Gross) Stress	s Level o	f FALSTA	FF Spect	rum (Step :	32)		
34	ksi	(_		234.4	MPa)		
Specimen Identification	:	Mir-	204	-,			
Specimen Bending at Min	imum Load	: <u>/</u>	lone	_ %			
Specimen Bending at RMS	Mean Loa	d:	£ 53	%			
RMS Mean Cyclic Frequence	cy:	, ,	0.5	Hz			
Number of Flights to In	itial Vis	ible Cra	ck:	111-1		Flight	s
Size of Initial Visible	Crack:		14	in. (am)
Number of Flights to Car	tastrophi	c Failur	e:	773	7	Flight	s
Fatigue-Crack-Initiation	n Site:		· · · · · · · · · · · · · · · · · · ·				
	 	Phor	l c		<u></u>	Sketc	
Description of Abnormal:	ities: _		6186				Bed Sek

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

1.	Date of Test: Start 7-11-78 End 7-12-78
2.	Manufacture/Model of Fatigue Test Machine:
3.	Test Temperature: OF (OC OC
4.	Relative Humidity: (%)
5.	Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
	ksi (
6.	Specimen Identification:
7.	Specimen Bending at Minimum Load: 1/6.76 %
8.	Specimen Bending at RMS Mean Load: 253 %
9.	RMS Mean Cyclic Frequency: Hz
10.	Number of Flights to Initial Visible Crack: Flights
	Size of Initial Visible Crack: // /-) in. (mm
	Number of Flights to Catastrophic Failure:
	Fatigue-Crack-Initiation Site:
	See Photo Sketch
14.	Description of Abnormalities: //s/) €
15.	Description of Buckling Restraint (If Used):

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

1.	Date of Test: Start 7-12-78 End 7-13 78
2.	Manufacture/Model of Fatigue Test Machine: 2175 22 1219
3.	Test Temperature: OF (27C °C)
4.	Relative Humidity:(%)
5.	Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
6.	Specimen Identification: AF-112
7.	Specimen Bending at Minimum Load:
8.	Specimen Bending at RMS Mean Load:
9.	RMS Mean Cyclic Frequency: 10 5 Hz
0.	Number of Flights to Initial Visible Crack: /// Flights
1.	Size of Initial Visible Crack:in. (mm)
2.	Number of Flights to Catastrophic Failure: 543/ Flights
3.	Fatigue-Crack-Initiation Site:
	Jee Photo Sketch
4.	Description of Abnormalities: 1/2000
5.	Description of Buckling Restraint (If Used):

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

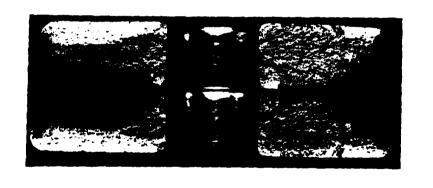
1.	Date of Test: Start 7-13-78 End 7-14-7	(
	Manufacture/Model of Fatigue Test Machine:		
3.	Test Temperature: 6 6 0p (· - .	°C)
4.	Relative Humidity: (%)		
5.	Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)		
	ksi (KPa)		
6.	Specimen Identification:		
7.	Specimen Bending at Minimum Load:		
8.	Specimen Bending at RMS Mean Load: 7		
9.			
٥.	Number of Flights to Initial Visible Crack:	_ Flight	s
	Size of Initial Visible Crack: // d in. (
	Number of Flights to Catastrophic Failure:		
	Fatigue-Crack-Initiation Site:		
	sec Photo	Sketc	h
4.	Description of Abnormalities: //c/16		
5.	Description of Buckling Restraint (If Used):		

APPENDIX II

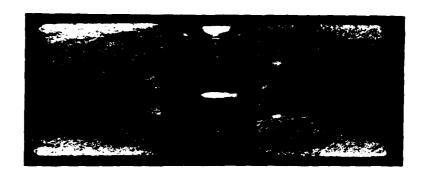
MACROGRAPHS OF FAILURE SURFACES



SPECIMEN AF-26



SPECIMEN BF-242



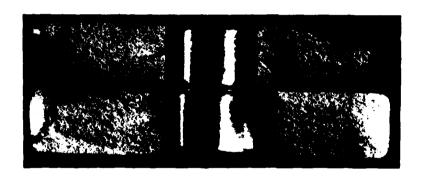
SPECIMEN BF-235



SPECIMEN BF-224



SPECIMEN AF-45



SPECIMEN AF-47



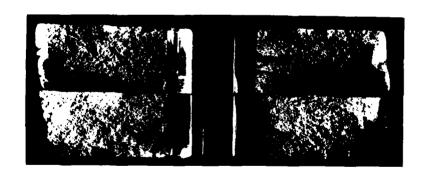
SPECIMEN BF-227



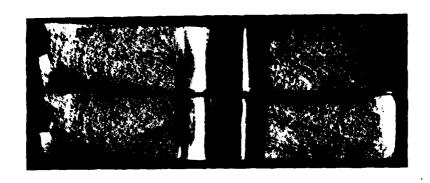
SPECIMEN AF-122



SPECIMEN BF-281



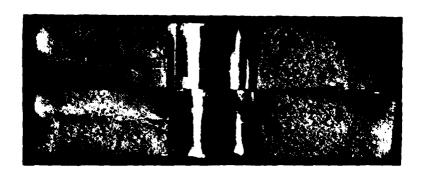
SPECIMEN AF-78



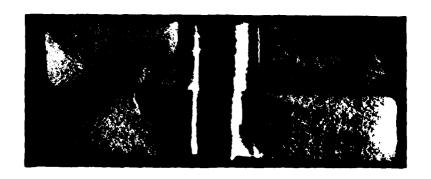
SPECIMEN AF-136



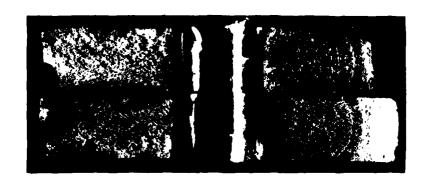
SPECIMEN BF-305



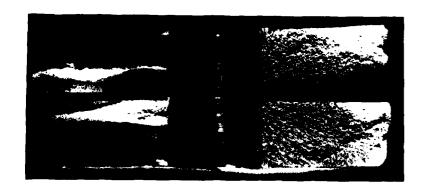
SPECIMEN BF-323



SPECIMEN BF-228



SPECIMEN AF-123



SPECIMEN AF-88



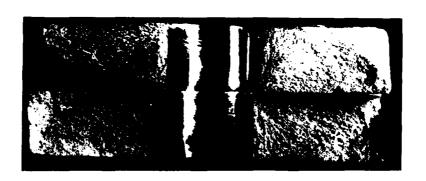
SPECIMEN AF-43



SPECIMEN AF-138



SPECIMEN AF-114



SPECIMEN BF-223



SPECIMEN AF-112

APPENDIX E

CRITICALLY LOADED HOLE TECHNOLOGY PILOT PROGRAM

PHASE III REPORT FOR PERIOD APRIL 1979 - AUGUST 1979

BATTELLE COLUMBUS LABORATORIES 505 KING AVENUE COLUMBUS, OHIO 43201

September 1979

METCUT RESEARCH ASSOCIATES, INC., PURCHASE ORDER NO. 65474

INTRODUCTION

A pilot program has been initiated by the AGARD SMP Subcommittee on Critically Loaded Hole Technology in an effort to promote a mutual confidence in fatigue test data generated by participating countries. The successful completion of the program will lead to a more uniform quality of fatigue testing and evaluation of critically loaded hole parameters among its participants. The objectives of the three-phase program are as follow:

- Phase I Generate baseline, open hole, fatigue data
 in order to examine laboratory-to-laboratory
 variations
- Phase II Reaffirm the exchangeability of baseline data and investigate the effect of hole quality on open hole fatigue specimens
- Phase III Conduct independent fatigue evaluations of various fatigue-improvement fasteners and exchange data.

Participants in the program included representatives from Belgium, France, Germany, Italy, Netherlands, Sweden, United Kingdom, and the United States. All specimens for the program are to be prepared by Metcut Research Associates, Inc., from a single heat of 7050 material procured from Alcoa in the form of 7050-T76 bare sheet, 0.196-inch (5 mm) thick. Battelle's Columbus Laboratories (BCL) has been designated as the USA testing facility.

The report contained herein details the results of the Phase III effort.

GENERATION OF THE FALSTAFF SPECTRUM

In order to insure that all participants apply the same cyclic loads, each country was to test specimens under the FALSTAFF (Fighter Aircraft Loading STAndard For Fatigue). The BCL fatigue load control program was generated using the computer program detailed in the definitive description of the FALSTAFF spectrum, dated March 1976. The details of the BCL load control program generation were presented in the Phase I report dated February 1978.

PROGRAM CONTROL

This section describes the BCL system and equipment used to apply and control FALSTAFF program loads. In general, the HP 2100 computer provides load steps to a hybrid unit which generates a constant ramp rate function for the MTS 20,000-pound (88,960 N) closed-loop electrohydraulic fatigue machine. A null pacing unit makes a constant comparison of programmed load-to-load cell output and signals the hybrid unit when the programmed load has been reached, at which time the ramp direction is reversed and a new load is called from the computer. This procedure continues until a preprogrammed number of flights has been reached or until the test specimen fails. A graphic presentation of the program control cycle is presented in Figure 1. A secondary computer subroutine, STATS, makes it possible to determine the flight number, total number of cycles, and percent of a pass through the spectrum completed at the moment of questioning.

Pretest Checks

Prior to initiating the fatigue test program, pretest checks were made (as in Phase I) using the Phase I spare specimen (without a hole in the test section) instrumented with two strain gages located near the specimen edge on each face of the specimen. The output of the four strain gages made it possible to determine specimen bending and buckling (if any existed) and to confirm that dynamic loads matched static calibration loads.

Bending Check

Strain gage data were obtained at incremental load steps for loads to an equivalent of 38 ksi (262 MPa) maximum and -19 ksi (131 MPa) minimum. Data were obtained for three loading cycles. The strain-load data were submitted to a linear regression analysis with resulting R² statistic values ranging from 1.000 to .9994. Strain values were computed for the load equivalent of 30 ksi (206.85 MPa) gross stress. Analysis of the strain values indicated that the maximum error due to specimen bending was 2.50 percent. Analysis of the compressive load data indicated that no buckling could be detected.

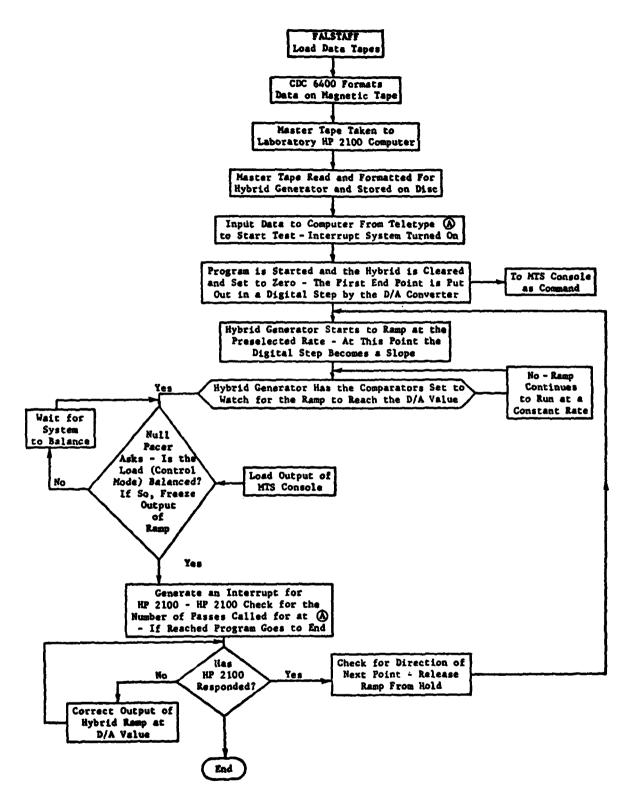


FIGURE 1. PROGRAM CONTROL CYCLE

Static-Dynamic Loads Check

Comparison of strain gage output and calibrated load cell output indicated a maximum axial load error of 1.50 percent at 38 ksi (262 MPa) static load. Application of cyclic loads at the same level provided the same strain outputs at frequencies of 1, 5, and 10 Hz.

FALSTAFF Loads Check

The specimen was subjected to FALSTAFF loads cycling and ramp rate and MTS unit controls were adjusted so that fatigue machine load output matched the command signal (reference Figure 2). Once setup was complete the controls were locked and not changed during the rest of the test program. The mean cyclic rate was determined to be 10.5 Hz. In addition, staff members of the University of Dayton Research Institute made load and spectrum accuracy measurements. These data are reported separately.

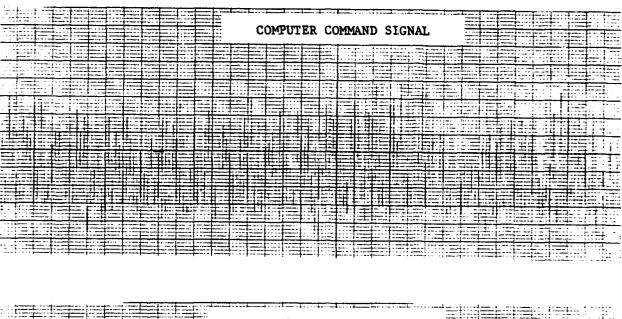
TEST RESULTS

Fatigue Load Selection

Tests were conducted on specimens assembled by Metcut Research Associates. In order to determine a reference stress level for the low-load transfer specimen used in this Phase, these specimens were assembled using HiLok fasteners installed in a tight interference fit. Analysis of the data presented in Table I indicated that a reference stress of 51 ksi (351.6 MPa) would provide a fatigue life of approximately 10,000 FALSTAFF flights to failure.

TABLE I. LOAD LEVEL DETERMINATION

Specimen Number	Reference Stress, ksi/MPa	Flights to Failure	
2	57.0/393.0	1,632	
4	50.0/344.7	11,371	
6	51.0/351.6	10,970	
7	52.0/358.5	7,210	



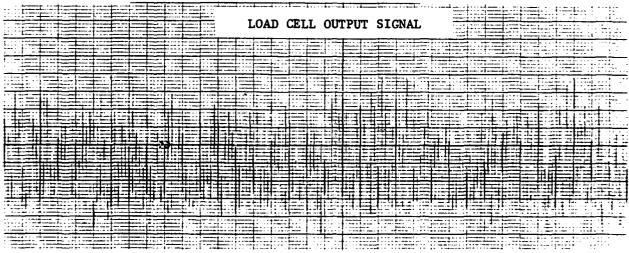


FIGURE 2. COMPUTER COMMAND AND LOAD CELL SIGNAL COMPARISON FOR A PORTION OF THE TEST ON SPECIMEN J8-J43

Fatigue Test Program

Fatigue test specimens, as supplied by Metcut Research Associates, Inc., were selected at random from all three specimen types (K-Lobe fasteners in high and low quality holes and blind fasteners). All specimens were cycled at a reference stress of 51.0 ksi (351.6 MPa). A summary of the fatigue test data is presented in Table II and detailed data sheets are included as an appendix to this report.

NOTE: The data for the blind fastener specimen J44-J54, which failed at 3,764 flights, is not tabulated because it was tested at 42 ksi (289.6 MPa) instead of the required level.

TABLE II. FATIGUE TEST RESULTS*

Specimen Number	Flights to Failure						
K-Lobe in High-Quality Holes							
J41-J48	15,160						
J20-J42	12,344						
J8-J43	9,964						
J2-J17	12,734						
J45-J50	7,597						
J25 – J35	7,080						
	Mean Life 10,813						
Standard	Deviation 3,160						
K-Lobe in Lo	w-Quality Holes						
J4-J33	9,164						
J18-J12	9.924						
J47-J10	17,228						
J22 - J26	6,164						
J13-J53	10,164						
J2 - J16	13,755						
	Mean Life 11,070						
Standard	Deviation 3,875						
Blind	Fasteners						
J32-J51	1,364						
J6-J40	1,964						
J5 ~ J55	1,534						
J7 - J36	1,544						
J24-J30	1,597						
	Mean Life 1,600						
Standar	rd Deviation 221						

^{*} FALSTAFF reference stress - 51 ksi (351.6 MPa)

APPENDIX 1

DETAILED DATA SHEETS

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

Date of Test: Start	May 5, 1979	E	nd <u>May 6.</u>	1979
Manufacture/Model of F	atigue Test Mac	hine: MT	S	
Test Temperature:	70	of (21	°C)
Relative Humidity:	42	(%)		
Reference (Gross) Stre	ss Level of FAL	STAFF Spectr	um (Step 32)	
51.0	ksi.	(351.6	MPa)
Specimen Identificatio	n: <u>8 (5</u>	A) J25-J3	5	
Specimen Bending at Mi	nimum Load:	None	_ %	
Specimen Bending at RM	S Mean Load:	2.6	_ %	
RMS Mean Cyclic Freque	ncy:	10.5	Hz.	
Number of Flights to I	nitial Visible	Crack:		Flights
Size of Initial Visibl	e Crack:		in. (mm)
Number of Flights to C	atastrophic Fai	lure:	080	Flights
Fatigue-Crack-Initiati	on Site:3	/8" below	bottom fast	ener
	00	fer Fa	·	Sketch
Description of Abnorma	lities:			
				
Description of Bucklin				
	g Kestraint (It	Used):		

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

1.	Date of Test: Start _	May 8,	1979	End	May 9,	1979	
2.	Manufacture/Model of Fa	-	-			KIP	_
3.	Test Temperature:	70	of	(21	°(:)
٠.	Relative Humidity:	42	(%)				
.	Reference (Gross) Street	ss Level of FA	LSTAFF Spe	ectrum (St	ep 32)		
	51.0	ksi	(3	51.6	MPa)	•	
•	Specimen Identification	n: <u>5</u>	J45	-J50			_
•	Specimen Bending at Min	nimum Load:	None	7.			
•	Specimen Bending at RMS	S Mean Load:	2.6	%			
	RMS Mean Cyclic Frequen	ncy:10	.5	Hz			
•	Number of Flights to In	nitial Visible	Crack:			Flights	
•	Size of Initial Visible	Crack:		in.	(a)
•	Number of Flights to Ca	itastrophic Fa	ilure: _	7597	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	Flights	
	Fatigue-Crack-Initiation	on Site:					
		E	7		}	Sketch	_
	Description of Abnormal						<u> </u>
,	Description of Buckling	Restraint (I	f Used):				

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

1.	Date of Test: Start	July 13,	L979	End _	July 13.	1979
2.	Manufacture/Model of Fa	tigue Test M	lachine:	MTS	50 KIP	
3.	Test Temperature:	70	o _F	(21	°C)
4.	Relative Humidity:	50	(7.)			
5.	Reference (Gross) Stres	s Level of F	ALSTAFF Sp	ectrum ((Step 32)	
	51.0	ksi	(3	51.6	MPa)	
6.	Specimen Identification	: 10	J24-J30			سياكسين كنجاسة
7.	Specimen Bending at Min	imum Load:	None	7.		
8.	Specimen Bending at RMS	Mean Load:	2.6	7.		
9.	RMS Mean Cyclic Frequen	су:	10.5	Hz	:	
0.	Number of Flights to In	itial Visibl	e Crack:			Flights
1.	Size of Initial Visible	Crack:	·	i	n. (mm)
2.	Number of Flights to Ca	tastrophic F	ailure: _	1597		Flights
3.	Fatigue-Crack-Initiatio	n Site:				
						
				rap		Sketch
t.	Description of Abnormal	ities:				
5.	Description of Buckling	Restraint (If Used):		· · · · · · · · · · · · · · · · · · ·	

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

Date of Test: Start _	July 16,	1979	End	July	17,	1979	
			MTS	50	KIP		
Test Temperature:	70	op	(21			°C)
Relative Humidity:	50	(%)					
Reference (Gross) Stre	ss Level of F	ALSTAFF Spe	ectrum (Step 32)		
42.0	ksi	(289	.6	M	Pa)		
Specimen Identification	n: <u>11</u>	J44-J54					
Specimen Bending at Mi	nimum Load:	None	%				
Specimen Bending at RM	S Mean Load:	2.6	%				
RMS Mean Cyclic Freque	ency:	10.5	Hz				
Number of Flights to I	nitial Visibl	e Crack: _				Fligh	ts
Size of Initial Visibl	e Crack:		i	n. (mm)
Number of Flights to C	atastrophic F	ailure: _	3764			Fligh	ts
Fatigue-Crack-Initiati	on Site:						
				·			
	<u> </u>	1 3	_ <i>HEP</i> 9				
		4				Sket	ch
	1	7=/	_				
Description of Abnorma	lities:	Wrong Stre	ess				
Description of Bucklin	g Restraint (If Used):					

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

Date of Test: Start	July 17,	1979	End Ju	ly 18, 19	79
Manufacture/Model of	•	fachine:	MTS	50 KIP	
Test Temperature:	69	oř	(20		
Relative Humidity:	49	(%)			
Reference (Gross) St	ress Level of I	ALSTAFF Spe	ectrum (Step	32)	
51	ksi	(351.6	MPa)	
Specimen Identificat	ion:1	2 ј4	i-J33	·	
Specimen Bending at	Minimum Load:	None_	%		
Specimen Bending at	RMS Mean Load:	2.6	7.		
RMS Mean Cyclic Freq	uency:	10.5	Hz		
Number of Flights to	Initial Visib	le Crack:			Flights
Size of Initial Visi	ble Crack:		in.		mm)
Number of Flights to	Catastrophic l	Failure: 9	,164.06		Flights
Fatigue-Crack-Initia	tion Site:				
	-				Sketch
Description of Abnor	malities:				
Description of Buckl	ing Restraint	(If Used):			

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

1.	Date of Test: StartJuly 18, 1979	End July 19, 1	.979
2.		MTS 50 KIP	
3.	Test Temperature: 71 op	(°C)
4.	Relative Humidity: 42 (%)		
5.	Reference (Gross) Stress Level of FALSTAFF Spect	trum (Step 32)	
	51ksi (35]	1.6 MPa)	
6.	Specimen Identification: 13 J18-	-J12	
7.	Specimen Bending at Minimum Load: None	7.	
8.	Specimen Bending at RMS Mean Load: 2.6	%	
9.	RMS Mean Cyclic Frequency: 10.5	Hz	
10.	Number of Flights to Initial Visible Crack:		_ Flights
11.	Size of Initial Visible Crack:	in. (om)
12.	Number of Flights to Catastrophic Failure:	9,923.66	_ Flights
13.	Fatigue-Crack-Initiation Site:		
			Sketch
		· · · · · · · · · · · · · · · · · · ·	Sketch
14.	Description of Abnormalities:	· · · · · · · · · · · · · · · · · · ·	Sketch
	Description of Abnormalities: Description of Buckling Restraint (If Used):	· · · · · · · · · · · · · · · · · · ·	Sketch

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

Date of Test: Start	July 19,	1979	_ End _	July	20,	1979	
Manufacture/Model of			MTS	50	KIP		
Test Temperature:	70	op	(21			°C)
Relative Humidity:	40	(%)					
Reference (Gross) St	ress Level of I	ALSTAFF Sp	ectrum (Step 32)	ı		
51	ksi ksi	(35	1.6	MP	(a)		
Specimen Identificat	ion:	14	J47-	J10			
Specimen Bending at	Minimum Load:	_None	%				
Specimen Bending at	RMS Mean Load:	2.6					
RMS Mean Cyclic Freq	uency:	10.5	Hz				
Number of Flights to	Initial Visib	le Crack:				_ Fligh	ts
Size of Initial Visi	ble Crack:		1	n. (mm)
Number of Flights to	Catastrophic I	ailure: _	17,	228.46		_ Fligh	ts
Fatigue-Crack-Initia	tion Site:						
							
		6		:			
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				i			
Description of Abnor	malities:		يم. 		_		
Description of Buckl	ing Restraint ((If Used):					
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AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

Date of Test: Start _	July 20. 1	979	End	uly 21.	1979
Manufacture/Model of F	atigue Test M	achine:	MTS	50	KIP
Test Temperature:	70	o _F	(
Relative Humidity:	44	(%)			
Reference (Gross) Stre	ss Level of F	ALSTAFF Spe	ectrum (St	ep 32)	
51	ksi	(351	.6	MPa)	
Specimen Identificatio	n: <u>15</u>	J22-J	26		
Specimen Bending at Mi	nimum Load:	None	%		
Specimen Bending at RM	S Mean Load:	2.6	%		
MS Mean Cyclic Freque	ncy:	10.5	Hz		
Number of Flights to I	nitial Visibl	e Crack:			Flights
Size of Initial Visibl	e Crack:		in.		mm)
Number of Flights to C	atastrophic F	ailure:	6,164.	42	Flights
!atigue-Crack-Initiati	on Site:				
	, 				
	- ^ ·				Sketch
	<u>` </u>				
Description of Abnorma	lities:	-==	}		
theran as			·		· · · · · · · · · · · · · · · · · · ·
Description of Bucklin	g Restraint (If Used):			
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AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

Date of Test: Start July 21, 1	L979	_ End _	July 22,	1979
Manufacture/Model of Fatigue Test M		MTS	50 K	IP
Test Temperature: 70	0 7	(21	°C)
Relative Humidity: 47	(%)			
Reference (Gross) Stress Level of F	'ALSTAFF Sp	ectrum (Step 32)	
51 ksi	(35	L-6	MPa)	
Specimen Identification:	16	J13-J	53	
Specimen Bending at Minimum Load:	None	7.		
Specimen Bending at RMS Mean Load:	2.6	%		
RMS Mean Cyclic Frequency:	10.5	Hz		
Number of Flights to Initial Visible	le Grack:			Flights
Size of Initial Visible Crack:		i	n. (mm)
Number of Flights to Catastrophic E	eilure:	10,16	4.42	Flights
Fatigue-Crack-Initiation Site:				
		. !		Sketch
Description of Abnormalities:				
		··-		
Description of Buckling Restraint	(If Used):			
			· · · · · · · · · · · · · · · · · · ·	

AIR FORCE/AFRL - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

Date of Test: Start July 23, 1	.979 	End July 2	24, 1979
Manufacture/Model of Fatigue Test Ma	schine:	50 KIP	MTS
Test Temperature: 70	oh	(21	°C)
Relative Humidity: 50			
Reference (Gross) Stress Level of FA	ALSTAFF Spec	ctrum (Step 32)
51ksi	(351	.6M	Pa)
Specimen Identification: 17	J2-	-J16	
Specimen Bending at Minimum Load:			
Specimen Bending at RMS Mean Load:	2.6	%	
RMS Mean Cyclic Frequency:			
Number of Flights to Initial Visible	Crack:		Flights
Size of Initial Visible Crack:		in. (san:)
Number of Flights to Catastrophic Fa	ilure: 1	3,754.98	Flights
Patigue-Grack-Initiation Site:			
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-	!] '	- Ci	Sketch
	1	1	
Description of Abnormalities:		•	
Description of Buckling Restraint (1	(f Used):		

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

1.	Date of Test: StartJuly 2	4, 1979	End	
2.	Manufacture/Model of Fatigue Tes	it Machine: _	50 KIP	MTS
3.	Test Temperature: 70	ok	(21	°C)
4.	Relative Humidity: 50	(%)		
5.	Reference (Gross) Stress Level of	of FALSTAFF Spe	ectrum (Step 32)	
	51 ksi	(351	6 MP	1)
6.	Specimen Identification: 6	J32-J5	1	
7.	Specimen Bending at Minimum Load	l: None	<u> </u>	
8.	Specimen Bending at RMS Mean Los	id: 2.6	%	
9.	RMS Mean Cyclic Frequency:	10.5	Ha	
10.	Number of Flights to Initial Vis	ible Crack:		Flights
11.	Size of Initial Visible Crack:		in. (am)
12.	Number of Flights to Catastrophi	c Failure:	1,364.06	Flights
13.	Fatigue-Crack-Initiation Site:			·····
			·····	·
		1		
			· · ·	Sketch
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14.	Description of Abnormalities:	<u></u>	1	
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15.	Description of Buckling Restrain	t (If Used):		
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AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

est Temperature:	70 50		•	F (2:	L	0(
lative Humidity:	50						`
·			((%)			
eference (Gross) Stress	s Level o	of FA	LSTAFF	Spectr	um (Ste	p 32)	
51	ksi		<u>_</u>	351.6		MPa)	
ecimen Identification	:	7		J6-J	140	··	
ecimen Bending at Min	imum Load	i: _	None	<u> </u>	_ %		
ecimen Bending at RMS	Mean Los	ıd: ˌ	2.6		_ %		
					Hz.		
mber of Flights to In	itial Vis	sible	Crack	·			_ Flights
ze of Initial Visible	Crack:				in.	(
mber of Flights to Car	tastrophi	lc Fa	ilure:	1,	964.06		_ Flights
tigue-Crack-Initiation	n Site:		. <u>.</u>				
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							FAI 11 Sk
		-		سير()	+	• •	24
escription of Abnormal:	Lties: _					- 1	}
	ecimen Identification ecimen Bending at Min: ecimen Bending at RMS S Mean Cyclic Frequence mber of Flights to In: ze of Initial Visible mber of Flights to Car tigue-Crack-Initiation	ecimen Identification: ecimen Bending at Minimum Load ecimen Bending at RMS Mean Load S Mean Cyclic Frequency: mber of Flights to Initial Vis ze of Initial Visible Crack; mber of Flights to Catastrophi	ecimen Identification: 7 ecimen Bending at Minimum Load: ecimen Bending at RMS Mean Load: S Mean Cyclic Frequency: mber of Flights to Initial Visible ze of Initial Visible Crack: mber of Flights to Catastrophic Fatigue-Crack-Initiation Site:	ecimen Identification: 7 ecimen Bending at Minimum Load: None ecimen Bending at RMS Mean Load: 2.6 S Mean Cyclic Frequency: 10.5 mber of Flights to Initial Visible Crack ze of Initial Visible Crack: — mber of Flights to Gatastrophic Failure: tigue-Crack-Initiation Site:	secimen Identification: 7 J6-J ecimen Bending at Minimum Load: None ecimen Bending at RMS Mean Load: 2.6 S Mean Cyclic Frequency: 10.5 mber of Flights to Initial Visible Crack: ze of Initial Visible Crack: mber of Flights to Catastrophic Failure: 1, tigue-Crack-Initiation Site:	secimen Identification: 7 J6-J40 ecimen Bending at Minimum Load: None 2 ecimen Bending at RMS Mean Load: 2.6 2 S Mean Cyclic Frequency: 10.5 Hz mber of Flights to Initial Visible Crack:	secimen Identification: 7

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

Date of Test: Start	July 25, 19	79	End July 25.	1979
Manufacture/Model of	Fatigue Test Ma	chine:	50 KIP	MTS
Test Temperature:	70	oā	(21	°c)
Relative Humidity:	52	(%)		
Reference (Gross) Str	ess Level of PA	LSTAFF Spect	rum (Step 32)	
51	ksi	(351.	6 MPa)	
Specimen Identificati	on: <u>8</u>	J5-	J55	
Specimen Bending at M	inimum Load:		_ %	
Specimen Bending at R	MS Mean Load:	2.6	_ %	
RMS Mean Cyclic Frequ	ency:1	.0.5	Hz	
Number of Flights to	Initial Visible	Crack:		Flights
Size of Initial Visib	le Crack:		in. (ma)
Number of Flights to	Catastrophic Fa	ilure:	1,534.34	Flights
Fatigue-Crack-Initiat	ion Site:			
		· · · · · · · · · · · · · · · · · · ·	1 11.11	
			المركب إ	
		•		Sketch
		سر	44	
Description of Abnorm	alities:			
			· · · · · · · · · · · · · · · · · · ·	_
Description of Buckli	ng Restraint (I	f Vsed):		

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

•	Date of Test: Start July 25, 197	9	En	d	July 2	7. 1979
١.	Manufacture/Model of Fatigue Test Mach			MTS	50	KIP
١.	Test Temperature: 70	of	(_		21	•c)
٠.	Relative Humidity: 52					
i .	Reference (Gross) Stress Level of FALS	STAFF S	pectru	m (St	ep 32)	
	51ksi	(35	1.6_		MPa)	
.	Specimen Identification: 1	J4	1-J48			
٠.	Specimen Bending at Minimum Load:			7.		
	Specimen Bending at RMS Mean Load:	2.6		7.		
٠.	RMS Mean Cyclic Frequency:	10.5		Hz		
•	Number of Flights to Initial Visible C	rack:				Flights
•	Size of Initial Visible Crack:			in.		tum)
•	Number of Flights to Catastrophic Fail	ure:	15,1	60.5		Flights
•	Fatigue-Crack-Initiation Site:					
					Tal 20	לויס

		 -	•		j	Sketch
		_			\	1 85. 115
	Description of Abnormalities:					in The
_					E	

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

1.	Date of Test: Start July 27, 1	.979	_ End _	July 2	7. 1979
2.	Manufacture/Model of Fatigue Test M	achine:	MTS	50 KIP	
3.	Test Temperature: 68	of	(20	°C)
4.	Relative Humidity: 50				
5.	Reference (Gross) Stress Level of Fa	ALSTAFF S	ectrum (Step 32)	
	51ksi	(3	51.6	MPa)	
6.	Specimen Identification: 9	J7-J36			
7.	Specimen Bending at Minimum Load:		%		
8.	Specimen Bending at RMS Mean Load:	2.6	%		
9.	RMS Mean Cyclic Frequency:	10.5	Hz		
10.	Number of Flights to Initial Visible	e Crack:			Flights
11.	Size of Initial Visible Crack:		i	ı. (mm)
12.	Number of Flights to Catastrophic Fa	ailure: _	1,564	.06	Flights
13.	Fatigue-Crack-Initiation Site:		_		
			7		Sketch
14.	Description of Abnormalities:				
15.	Description of Buckling Restraint (If Used):			

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

1.	Date of Test: Start July 27,	1979	End _	July 28,	1979
2.	Manufacture/Model of Fatigue Test	Machine:	MTS	50 KIP	
3.	Test Temperature: 68	O.	(20	°C)
4.	Relative Humidity: 50	(%)			
5.	Reference (Gross) Stress Level of	FALSTAFF Spe	ectrum (Step 32)	
	51 ksi	(351	.6	MPa)	
6.	Specimen Identification: 2	J2-J42			
7.	Specimen Bending at Minimum Load:		%		
8.	Specimen Bending at RMS Mean Load:	2.6	7.		
9.	RMS Mean Cyclic Frequency:	10.5	Hz		
lO.	Number of Flights to Initial Visib	le Crack: _			Flights
11.	Size of Initial Visible Crack:	-*	i	a. (mm)
l2.	Number of Flights to Catastrophic	Failure:	12,344	.12	Flights
L3.	Fatigue-Crack-Initiation Site:				-
				7	Sketch
.4.	Description of Abnormalities:				
15.	Description of Buckling Restraint	(If Used):			

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

1.	Date of Test: Start July 30,	1979	End _	Jul	31, 1979
2.	Manufacture/Model of Fatigue Test	Machine:	MTS	50 KIP	
3.	Test Temperature: 68	of	(20	°C)
4.	Relative Humidity: 50	(2	,		
5.	Reference (Gross) Stress Level of 51		=	Step 32)	
	ksi	(351.6	MPa)	
6.	Specimem Identification: 3	J8	J43		
7.	Specimen Bending at Minimum Load:		7.		
3.	Specimen Bending at RMS Mean Load:	2.6	7.		
9.	RMS Mean Cyclic Frequency:	10.5	Hz.		
0.	Number of Flights to Initial Visib	le Crack:			Flights
1.	Size of Initial Visible Crack:		i	n. (mm)
2.	Number of Flights to Catastrophic	Failure:	9,96	4.06	Flights
3.	Fatigue-Crack-Initiation Site:				5
				-	·
			i .(.)	.). - ::-	Sketch
		!		··	
			!		
4.	Description of Abnormalities:				
					
5.	Description of Buckling Restraint	(If Used):			
					

AIR FORCE/AFML - METCUT RESEARCH SPONSORED AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

Date of Test: Start July 31, 1	979	End		
Manufacture/Model of Fatigue Test	Machine:	MTS	50 KI	P
Test Temperature: 70	oř.	(°C)
Relative Humidity: 50	(%)			
Reference (Gross) Stress Level of B	ALSTAFF Sp	ectrum (Step	32)	
<u>51</u> ksi	(3	51.6	_MPa)	
Specimen Identification:	4	J2-J17		
Specimen Bending at Minimum Load:		7.		
Specimen Bending at RMS Mean Load:	2.6	%		
RMS Mean Cyclic Frequency:	10.5	Hz		
Number of Flights to Initial Visibi	le Crack:			Flights
Size of Initial Visible Crack:		in.	<u></u>	mm)
Number of Flights to Catastrophic E	failure:	12,734.34		Flights
Fatigue-Crack-Initiation Site:				
	-			
			•	Sketch
	L			
Becoming of About 1111				
Description of Abnormalities:				
Description of Buckling Restraint ((If Used):			

APPENDIX F

APPENDIX

VERIFICATION OF LOADING ACCURACY FOR FALSTAFF LOAD SEQUENCE

As a part of the critically loaded hole program, the University of Dayton, USA, conducted a program to determine whether or not all participating countries were applying identical spectrum load levels at the agreed-to reference stress level.

A.1 METHOD OF VERIFICATION

The evaluation was conducted using a master load cell specimen which replaced the standard test specimen (Phase III) in the fatigue machine. Each participating laboratory applied one complete spectrum (200 flights) of FALSTAFF to the master load cell specimen using the same servo control and program setup as was used for the Phase III low load transfer specimen.

A histogram recorder (data acquisition system) was used to record the number of load reversals that occurred within a narrow range of the load. The band width for each range was one-fourth of a FALSTAFF load level. The recorder had 128 storage locations for the reversals that were peaks and 128 storage locations for the reversals that were valleys. A schematic diagram of the recording system is shown in Figure A.1.

A.2 DESCRIPTION AND FUNCTION OF EQUIPMENT

A.2.1 Master Load Cell Specimen

The master load cell specimen was designed to fit in the testing machines without any modification to the grip arrangement. The specimen was designed so that it had the same stiffness as the reverse double dog-bone low load transfer test specimen.

The master load cell specimen had two strain gage bridges; one of the bridges was calibrated traceable to the USA

Bureau of Standards and was used to calibrate the second bridge and the histogram recorder.

A.2.2 Histogram Recorder

The histogram recorder was a Sun Systems, Inc.

ADASTOR II Solid State Recorder with duplicate sections for the peak and valley histograms. The recorder had two analog to digital converters and two microprocessors, one each for the peak recorder and one for the valley recorder. The fact that there were two analog to digital converters and two processors caused some confusion because the number of peaks recorded did not always equal the number of valleys recorded. We expected that the number of peaks would have to equal the number of valleys since the program for the peaks was the same as for the valleys. The only reason for any difference would have to be due to a different requirement for the change in load to define a peak than to define a valley. Both recorders were programmed to require a change in load of 1.5 FALSTAFF steps to define a peak or valley.

During the recording phase of the program, there were several times when many more valleys than peaks were recorded. This difficulty was thought to be caused by low battery voltage, however, after the recording program was completed the ADASTOR II was returned to Sun Systems for analysis. Sun Systems reported that the analog to digital converter on the valley recorder was adding electronic noise to the signal and then processed by the microprocessor. Sun Systems replaced the A-D converter in the valley recorder and since that time we have not had any extra readings in the valley recorder. We have just now used the recorder on a test that lasted seven hours without a single error by the recorder and without recharging the batteries.

The introduction of the noise on the valley recorder signal may have caused some valleys to be recorded at a lower value than was actually applied to the specimen and we know that it caused additional valleys to be recorded. For these reasons we have not reported all of the valley data for one country.

A.3 RESULTS

The results of the study are presented in Table A.1. The first column in the table (labeled FALSTAFF) lists the expected number of peaks or valleys at the particular FALSTAFF load level. Note that all of these levels are integer levels. The other seven columns are the recordings from the seven countries that participated in the program.

In the following presentation of the results, no comments will be made, with reference to any one laboratory, about load levels seven and eight for the peaks and load levels five and six for the valleys. The zero load level for the FALSTAFF sequence is 7.527 and the first load in the sequence is level eight and the last load level in flight 200 is load level six. Because the various laboratories used different initial values before the sequence was started and also different techniques to stop after 200 flights, there was the problem of perhaps not having the first or last load reversal. In some laboratories, it was also possible that one or two of the taxi cycles were too small for the histogram recorder to identify a peak or valley. The taxi cycles were equal to two FALSTAFF levels and the histogram recorder required 1-1/2 levels to identify a peak or valley. Actually most countries had the exact number of peaks or valleys for levels five, six, seven, and eight and those that didn't were only in error by one or two counts.

I have banded the data by FALSTAFF load levels.

A.3.1 Countries 1, 2, 3, and 6

As one can see from an examination of the data in Table A.1, there doesn't appear to be any question about which programmed load levels correlate with the histogram recordings for the first three countries and Country No. 6.

A.3.2 Country 4

For Country No. 4, there is a question about the peaks at load levels 16 and 17 since load level 16 has five

extra peaks and load level 17 has five too few peaks, also load level 12 has two extra peaks whereas load level 13 is missing two. There is no way from the histogram data to conclude if these loads are programmed incorrectly or if the incorrect load was applied by the hydraulics or for that matter if the histogram recorder assigned these few peaks to the wrong memory cell. The valley data for column four also shows an extra valley in load level 12 and one too few at load level 13. Because there isn't any separation between the valley recording at load levels 12 and 13 it is impossible to say whether one of the recordings (counts) at load level 12.25 was programmed for load level 13 or load level 12. The number 28 recorded for load level 12.25 could be interpreted as one valley intended for level 13 and 27 intended for load level 12.

A.3.3 Country 5

The histogram recordings reported in column five required more deduction to assign the numbers to the bands. first page of peaks has a one to one correspondence between the expected and recorded numbers. The recordings at load levels 15.5, 16.5, 17.5, 18.5, and 19.5 had to be divided between the next higher and lower integer levels to make the histograms correlate. The difficulty here is that one cannot say if some of the peaks recorded at 15.25, 16.25, 17.25, 18.25, and 19.25 were not programmed to be at the next higher integer level, however, since at the other load levels there was not this great a variation we assumed that the overlap was only in the one level, i.e., half way between the integer levels. This assumption made all of the recordings correlate with the expected values except load level 15 was one short and load level 13 was two short. The same procedure was used for the valleys. All of the recordings could be assigned to one of the load levels except level 12 was short four valleys.

A.3.4 Country 7

The data from Country No. 7 is the only set which contains an excess of counts in the peaks recorder. Some load levels contained the correct number of peaks (levels 32, 30, 29,

25, 22, 8, and 7) and some other levels were only off a few counts (levels 26, 21, 18, 14, 13). Based on the number of load levels that had the correct or nearly correct number of peaks, I think one can state that the spectrum generation was correct and that the hydraulic-servo system was capable of applying the correct load levels. There does appear to be a question as to what caused the extra counts in the peak recorder. At no other time, before or after this recording, did we get extra counts in the peak recorder. It is possible that the recorder malfunctioned or that the hydraulic-servo system was introducing a vibration in the system. Since only certain load levels were involved, it could be that the vibration was frequency dependent since the frequency used was a function of the range of the load change.

The histogram of the valleys was more irradic than the one for the peaks and had many more recordings than the peaks. Some of the load levels were correct (levels 24, 23, 20, 19, 17, 16, 3, 2, and 1) the other load levels except for level 18 had too many valleys. Some of these extra recordings could be due to the noise on the analog to digital converter and some of them could be due to a vibration in the test machine.

The data from Country No. 7 is not as meaningful as the others since the servovalve system used with the test machine and the spectrum frequency were not the same as was used for the Phase III test program.

A.4 DISCUSSION

The general conclusion from the verification program is that the various participating laboratories do quite a good job of applying spectrum loads.

Country No. 1 was excellent.

Country No. 2 was also excellent but with the peaks biased toward the high side and the valleys toward the low side. Too much span.

TABLE A.1. FALSTAFF HISTOGRAMS
PEAKS

	Falstaff	1	2	3	4	5	6	7
33								
32.5								
32				lando de sie de			Reconstant Section Control	
31.5		X (400) (100) (100)		30.				
31								
30.5					7	6	1 6	
30	7	—— 7—	7	1 6	·	——i—		
29.5			17	6			3, 10 Act v	5 2
29			10					2
28.5			15		21 3	13	10	
28	-24	 24	—- g			9	14	6
27.5				22		2		6 20 5
27	45	45	45					3
26.5			8		59 16	40	1 71	32.
26	76	 76	—-68—	 6	1	31	 4	
25.5				70	30 77	1		67 9
25	104	-108-	7			-13-	26	1
24.5					119	220	3.5.5	101
24	— 193——	—191—	193	11	$\frac{72}{2}$		155 38	3
23.5				182	*	12 2		64 188
23	-233	233	-211		22	= i};=		6
22.5				216.4	81	21 5 3		
22	-404	404	325 79	 26	81 298 25	253 —115—	322 82	
21.5				378		—115— 31 5		7 393
								4

TABLE A.1. FALSTAFF HISTOGRAMS
PEAKS CONTINUED

	Falstaff	1	2	3	4	5	6	7
21.5				6. 2.	267.3	14E	.	1.00
21				45				100
20.5				3.498	67	57 13		30 95
20	640	640	640	65	510 63	267 256	511	199
	-640			575	Į.	109	 129	216
19.5	7.5		958.4	45	787	8 4 364	737	580 4
19					142-	452 116	-216	-72
18.5			349		33 801	181 12 428	743	6867
18	 987	<u> </u>	 638	53	153	416	241	
17.5				934		122 9 10	3	402 586
17	E1151	188	978 173	4 ,,±	809 328	370 599	938 ** 213	1
16.5				11045	9	156 16 5		645 508
	,,,,,	1000	1244	20	764	313	930	
16	-1282	-1282	38	1244	514 9	731 205	350 2	1119
15.5			1997		1153	28 9 188	1523	279 2
15	-1999	_1999—	2_	12 1987	—837 <i>—</i> 9	-1423 370	476	775 1758
14.5			_			8	2002	358
14	-4145	3896	5 4140	64	2898 1245	144 —3199—	3903 241	2
13.5		249		4081	2	780 22	1	3819 325
13	_405 8	-3732-	-4052	70-	1670 -2381	72 —3146—	3949 —109—	127
_		326		3988	5	835		3867 '
12.5			5		128	12	486	61
12	493	446 47	488	490	364 3	385 96	—— 7 —	-1290 511
11.5			•		9	2	43	346
11	43	39	40		34	24 17		-292 24
10.5		4		43		17		£2
10								

TABLE A.1. FALSTAFF HISTOGRAMS
PEAKS CONCLUDED

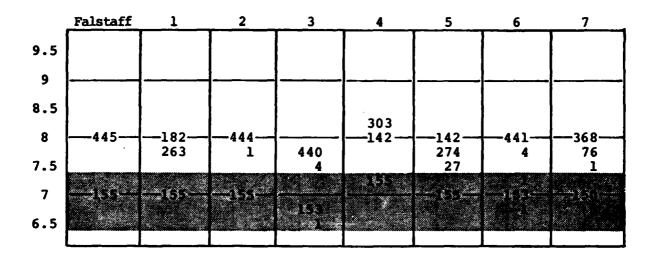


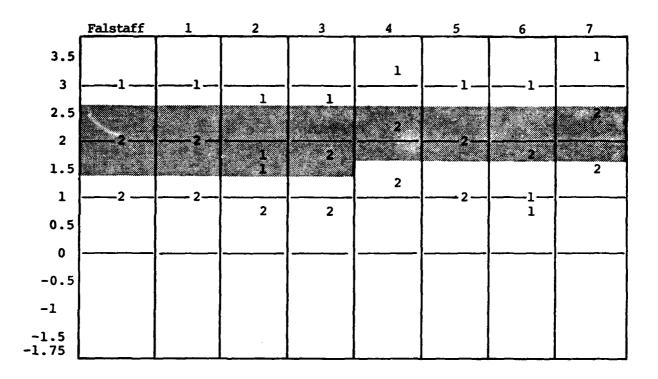
TABLE A.1. FALSTAFF HISTOGRAMS VALLEYS

	Falstaff	1	2	3	4	5	6	7
26								
25.5			_					
25	1	1	1		<u>1</u>	1-	1_	
24.5				1			1	
24		2	2		i	<u>1</u>	1	
23.5			-	2		1	1	2
23	з	3		3	3	<u>1</u>	1 1	
22.5				3		2	3	3
22	— 4 —		3-	4	2_	3	- 1	16
21.5	100	10	10		1 5	1	4 2	4
21	12	2_	2	12	 7	10 2	 6	5 25
20.5		1.3	22	12	8	2	9	25
20	—23—	—ii—	1-	23	12 3	9 5	1ī	8 15
19.5		23	36	~~	6	2 11	7 4	**
19	37	14-	i_	37	26	16 6	26	18 19
18.5		41		,	1	2 13	3 (
18	— 69 —	28	68	69	41 12	—3i—	61	49 18
17.5	5	15	6		14	5 3 37	1 10	
17	 135	—120 —	129	132	99 18	71— 16	10 124	109 20
16.5		10	23	3	4		20	4
16	234	-224-	<u> —211</u> —	232	-170- 46 -	2 36 	214	-225 9
15.5		7	104	. 2	9	19 2 62	28	4
15	327	—320 —	223	322	239 59	—144 <i>—</i> 88	299	305 8
14.5				5	23	33		

TABLE A.1. FALSTAFF HISTOGRAMS VALLEYS CONTINUED

	Falstaff	11	2	3	4	5	6	7
14.5				***************************************				
14	—511—	-511	<u> 425 </u>		- 44 326	74 —225—	42 469	_#7.
13.5	4		86	506 5	132 9	169 42		80
13	716—	—716 —	<u>619</u>		18 -472	82 —328—	65 651	
12.5			97	697 19	206 19	232 73		
12	-1445	-1445	-1290		28 -992	1 193 766	75 -1364	
11.5			155	1404 41	385 41	381 101 6	6	
11	-4387	-4387	3884		49 -3353	1154 2206	104 2528	
10.5			503	4228 159	906 79	829 192 24	1755	
10	-6711	-6 709	6 180		12 5678——	2143 -3789	48 -3139	
9.5		2	531	6425 286	926 95	634 121 2	3524	
9	1941	-1941	29		3 1382	324 -1194	23 -1078	
8.5			1911 1	1860 8 1	525 31	375 46 1	840	
8	-543	543	28	_	-190	33 —306—	12 —288—	
7.5			515	530 13	343 10	200	243	
7	36	1 35	7		31 —— 5 ——	18-	2 21	
6.5			29	36		17 26	13	
6	_508 <i></i>	266 —243—	508	-41-	441 —67——	269 —158—	2 —368—	
5.5				435 31		54	137	
5	-327	182 —145—			269 —58——	309	144	
4.5	***************************************	***************************************	161 166	321 4	henry (1944)	7	183	
4	6					2		
3.5			5 1	5		1	6	

TABLE A.1. FALSTAFF HISTOGRAMS
VALLEYS CONCLUDED



the an educate the state of the